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I-93 CENTRAL ARTERY (KNEELAND - CONGRES
DESIGN CONTRACT D011A
PRELIMINARY DESIGN REPORT

JANUARY 1991





COMMONWEALTH OF MASSACHUSETTS

CENTRAL ARTERY (I-93)/TUNNEL (I-90) PROJECT

I-93 CENTRAL ARTERY (KNEELAND - CONGRESS)
DESIGN CONTRACT D011A
PRELIMINARY DESIGN REPORT

JANUARY 1991

PREPARED FOR THE DEPARTMENT OF PUBLIC WORKS
BY BECHTEL/PARSONS BRINCKERHOFF

Stanko Bubanja, P.E.
Design Engineer

J. J. Brunetti, P. E.
Area Design Manager

K. K. See-Tho, P.E.
Design Manager

I-93 CENTRAL ARTERY

CONTRACT D011A
PRELIMINARY DESIGN REPORT

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2.0 Survey

The project mapping was prepared from aerial photography flown on August 2, 1987. The photographs were taken at an altitude to support 1 inch equals 20 feet (20 scale) mapping. Primary control was installed by the Global Positioning System (GPS) on an XYZ rectangular coordinate system and is a first order-class 1 survey.

Applicable survey information for the D011A contract is shown on the survey control sheets which are included in the preliminary design package.

3.0 Geotechnical

A separate geotechnical report has been prepared for this section, entitled "Preliminary Geotechnical Report". This report presents existing data, interpreted surburface conditions and a brief presentation of geotechnical design issues.

4.0 Civil Design

4.1 General

This section describes the civil considerations for design section D011A. D011A meets the South Bay Interchange (D009A) at the Central Artery (I-93) Northbound portal south of Kneeland Street at approximately station 84+25. Ramp C portal is located north of the mainline portal at approximately station 31+75, and Ramp DN lies between the two. Section D011A meets the D017A design section just north of Congress Street at station 106+70. The surface street, Atlantic Avenue, is included in the design. The tunnel alignment is controlled by several factors described in this section.

This preliminary design package covers the design and construction phases from wall construction through decking, excavation, tunnel construction, utility and surface street restoration, and opening the Central Artery Northbound. Considerations governing the design to be accomplished by the section designer are contained in this report.

4.2 Design Criteria

The Project Design Criteria establishes uniform design standards for the Central Artery (I-93)/Tunnel (I-90) Project, and are intended for use by all parties involved in the project design. The project shall be designed in accordance with the applicable provisions of these criteria. The civil section establishes the basic design criteria for geometric controls, clearance requirements, drainage, and surface streets to be constructed as part of the Central Artery project. The design criteria specify that the design shall meet the design standards of AASHTO, MDPW, City of Boston, or other local government agencies. Any exceptions to the design criteria must be submitted, through the Management Consultant, to the MDPW and the FHWA for approval.

Aligning the Central Artery to avoid the various existing structures to remain, and new structures which must be included, is difficult at best, and much effort was expended in meeting the project design criteria. These criteria were not always met, due to constraints imposed by the many structures slated to be accommodated. Where the criteria could not be met, a balance of the more important design considerations was achieved in order to rationally apportion the deviation and/or exceptions required. This report identifies those design considerations encountered while attempting to adhere to Project Design Criteria.

4.3 Project Datum

Horizontal control for roadway alignments is based on survey control points established and referenced to the Massachusetts State Plane Coordinate System, Mainline Zone, and North American Datum, 1983 (NAD 83). Vertical control is based on the National Geodetic Vertical Datum of 1929 (NGVD 1929), formerly US Coast and Geodetic Survey Mean Sea Level Datum of 1929. The project vertical datum plane is established at 100.00 feet below NGVD 1929.

4.4 Design Description

The constraints to the proposed alignment of D011A begin at Kneeland Street. The existing Wang buildings on the west side of Atlantic Avenue, and the proposed South Station Transportation Center (SSTC) ramps overhead, including its slurry wall to the east side, control the mainline location. The tunnel section is widened there to include Ramp C and Ramp DN. Major utilities in or crossing Atlantic Avenue include the 81" x 81" combined sewer at Kneeland Street. The South Station Headhouse at Summer Street severely restricts the curved alignment of the mainline, and further north the CANB tunnel penetrates the parking garage of the Federal Reserve Bank facility. The west slurry wall falls within the Peter Pan bus terminal overhang; however, this facility is scheduled for relocation before construction begins. CANB alignment then parallels the CASB tunnel between Summer Street and Congress Street under existing Atlantic Avenue.

The New East Side Interceptor (NESI) is a concern throughout; if it remains between the slurry walls as designed, it also becomes a vertical consideration. Nevertheless, it is difficult, if possible, to fit the NESI between the slurry wall and the existing building foundations. In addition, the proposed MBTA transitway must also fit within the slurry wall cross section between Northern Avenue and Essex Street. Finally, that portion of NESI in South Station is not slated for relocation; the relocated NESI will connect to the existing line at both ends of South Station.

4.4.1 Transition Curves, Superelevation and Cross Slope

The introduction of compound curves allows superelevation transition to be apportioned along the tangent and first curve(s), so that full superelevation is attained at the central curve.

The central 850' radius curve to the right in the D011A alignment has two transition curves of 4200' and 1800' radii, and their lengths are 150' and 100' respectively. This slightly exceeds a 2:1 ratio, while project design criteria calls for a 1.5:1 ratio. The 4200' radius curve requires a 0.027 ft/ft superelevation rate, the 1800' radius a 0.046 ft/ft superelevation rate, and the 850' radius central curve is the minimum allowed for 0.060 ft/ft superelevation for a 50 miles per hour design.

The length of transition required by the project design criteria for this curve ($e = 6\%$) equals 240' for four lanes, determined by the formula $L_d = WeP(1.5)(1.67)$, where $W = 12'$, $e = (0.06 - 0.02)$, and $P = 200$. Applying this length, and holding 6% cross slope at the PCC of the center curve, the required 2.7% for the 4200' radius curve and the 4.6% for the 1800' radius curve are not attained. Extending the L_d to 300' allows cross slopes at the two PCCs which more closely approximate the required superelevation rates. A 300' length was therefore used to transition from a 2% normal cross slope to the 6% full superelevation.

The curve to the left in the D017A section requires extending the D011A transition from 6% past 2%, yielding a 0.4% cross slope at Station 106+70, the limit of work. The mainline cross slope is a normal 2% at the nose with Ramp C. A 2% cross slope was therefore held for design of Ramp C, and for the design of Ramp DN at its nose with Ramp C.

4.4.2 Sight Shelves

The areas of curves where the radii are tight require a widened pavement on the inside edge to allow for adequate horizontal sight distance. This widened pavement is called a sight shelf, and its design is based on the radius, sight distance, and design speed.

The width required for the sight shelf is given by the formula $m = R[1 - \cos(28.65s/R)]$. This equals 17.7' for the 850' radius 50 miles per hour mainline curve, where $R = 807'$ and $s = 400'$ minimum. ($m = 24.66'$; therefore the sight shelf width equals 24.66' less 6' half lane less 1' shoulder = 17.7')

The position of the existing South Station foundation requires a certain slurry wall location, restricting the sight shelf to approximately 6' at that point. This widens to 12' in the central curve, satisfying a sight distance for a 45 miles per hour design. The 1800' radius curve requires a 4.4 to 9.0' sight shelf, and the 3300' and 4200' radii curves require none.

Horizontal sight distance design assumes a 6" height of an object in the roadway with an eye height of 3'6". A disabled vehicle would be more readily visible, however, since it could be seen over the safety walk. In this instance, the available sight shelf width would increase by the 3'2" width of the safety walk.

4.4.3 Entrance Gores

Ramp C merges with the mainline at CANB Station 94+00. The typical ramp detail shown on the drawings governs there, where the angle of taper is a function of the width at the nose. The resulting angle in this case directs the ramp edge very neatly into the 1750' radius curve of the mainline edge, the second transition curve of CANB, requiring no additional transition curve to effect the merge.

At the merge of Ramp DN with Ramp C, the angle of the two alignments is sufficient to accommodate the merge.

4.4.4 Geometric Controls

Vertical controls for design of the profiles are as constricting as the horizontal controls within the D011A project limits. The 81" x 81" combined sewer at Kneeland Street cannot be impacted. However, the Boston Water and Sewer Commission may allow its reconstruction adjacent to the existing location, which would preclude a temporary sewer. This crossing lies close to the CANB roof slab. Supply and exhaust vents in D011A are carried in the floor and roof sections, not in the walls.

The MBTA is currently designing the Fort Point Channel Underground Transitway, which will connect with South Station. Present status of their design shows the profile of the transitway diving immediately after leaving South Station in order to clear the relocated NESI line and the CASB (Dewey Square Tunnel) crossing under Essex Street. The transitway turnaround, that portion which affects CANB, must follow the same alignment for a certain distance, and then clear a proposed 24" combined sewer in Atlantic Avenue between East Street and Essex Street.

Although constraints are considerable in this location, studies by B/PB utility engineers indicate that it may be feasible to place NESI between the slurry wall and the adjacent buildings on the west side of Atlantic Avenue. There are also additional utilities, 24" and 42" sewers and a 30" gas main, being designed as replacement lines in Atlantic Avenue. The South Station MBTA Red Line station must be underpinned in order that the northbound Central Artery tunnel may be constructed beneath, as shown on the plans and profiles.

The Congress Street storm water pump station will be affected by the slurry wall, if not by the tunnel construction itself. The decision to retain the existing pump station or to relocate it elsewhere has not yet been made.

The alignment must pass below the MBTA transitway, before the transitway turns to the east, and above the MBTA Blue Line station at State Street in Section D017A, both of which affect the profile in Section D011A.

The decision to raise the South Bay Interchange from its underground location significantly affects the profile of CANB along Atlantic Avenue. This and the South Station underpinning require a 5.7% grade on the mainline, which is a design deviation.

The clearance throughout the mainline tunnel box provides 17' from the high side of the roadway surface to the bottom of the ceiling, which allows 14' for vehicles and 3' for overhead signs. The allowance for the ceiling is 1' throughout, and depending on location, depth, and geotechnical and structural considerations, the floor and roof slabs vary in thicknesses. Various existing and proposed structures will penetrate the roof or floor slabs, and design for these accommodations are addressed in the structural section of this report. The allowance for overhead exhaust vent requirements in the cross section is uniformly 4', with the one exception being at the location of the 81" x 81" combined sewer at Kneeland Street. The vent depth there was allowed to be no less than 2' in the CANB section. Nevertheless, the current design of the CANB profile and the 81" x 81" combined sewer reconstruction permit a vent depth of approximately 4'. (The Ramp C vent depth has been set at 4' minimum.)

4.5 Traffic Management

Four phases are anticipated for management of traffic during construction, reflected by the four construction phases shown on the plans. Slurry wall construction is anticipated to be accomplished in 10' to 20' lengths, leapfrogging along Atlantic Avenue. Traffic will be maintained on one side while construction is performed on the other. Underpinning of the South Station MBTA Red Line station and wall construction in the Federal Reserve Bank building can proceed simultaneously.

Intermediate supports or pin piles and cross bracing will be constructed, and decking placed between the completed wall sections, so that traffic can be maintained on the surface of the decking. The tunnel excavation and construction can then proceed below the decking. Utilities must be supported and maintained in place under the decking.

Following the backfill operation and reconstruction of the surface artery, traffic can be restored on Atlantic Avenue. Traffic management must include consideration of the resulting construction staging requirements which stem from the additional and/or changed traffic volumes and patterns, including that for side streets.

4.6 Design Exceptions

The design criteria for a 50 miles per hour design speed indicate a 17.7' sight shelf width is required through the 850' radius mainline curve. However, because of horizontal constrictions, a maximum 12' sight shelf is provided. This will be constructed of textured pavement of a color different than that for the traveled way.

Highway cross sections as stated in the Project Design Criteria for the Central Artery include provisions for desirable shoulder widths of 4' on the left and 10' on the right. Severe right of way restrictions, however, require that the tunnel cross section width be reduced to a minimum. The typical sections and details for the mainline tunnel, therefore, carry an allowance for 1' shoulders on the left and right.

Design criteria allow a maximum of 5% grades on the mainline. As a result of the underpinning operations at South Station and the vertical controls at South Bay Interchange, a 5.7% grade on CANB is required.

6.0 Construction Impact Mitigation

6.1 Introduction

Mitigation is an integral component of design and construction for the CA/T Project. The overall goal of the mitigation program is to minimize the disruptive effects of construction while maintaining the schedule, quality, and cost effectiveness of the project.

This section is intended to provide the SDC with information as well as guidelines and requirements to aid in the development of mitigation plans and specifications. It contains 1) a description of existing conditions in the project area, highlighting those that are particularly sensitive to mitigation issues, and 2) specific areas within the contract boundaries which must be addressed with mitigation strategies.

The SDC shall work with CA/T mitigation staff throughout the final design process to ensure effective mitigation measures are integrated into the final design. Mitigation reviews will be conducted throughout the design and construction process.

6.2 Existing Conditions

6.2.1 General Description (see attached mitigation map)

The D011A contract area is bordered to the north by the financial district, to the south by the highway loops of the Massachusetts Turnpike, and to the west by the Leather District and Chinatown. The area's western side is largely comprised of small commercial and office space, galleries, restaurants and minor residential uses, while its eastern side is dominated by South Station. Two high rise office towers, One Financial Center and the Federal Reserve Bank, connect the area's southern border to the financial district. The presence of South Station and the Peter Pan Bus Station, as well as the area's direct connection to the Mass Turnpike east and west, and to I-93, make the D011A contract area an important transportation node.

1. South Station Transportation Center (SSTC)

- South Station (and open land to be used for its proposed expansion) lies along the east side of Atlantic Ave. from Summer Street to just south of Kneeland Street.
- The Commuter Rail and Amtrak, with connections south and west operate out of South Station, as does a Red Line rapid transit station. Within the station are food vendors/restaurants, services and push cart vendors.
- Commuter bus lines park and pick up passengers along the eastern curb of Atlantic Ave next to the Station.
- The above activities generate a large amount of pedestrian traffic primarily during AM and PM rush hours and at lunch time. A large pedestrian volume crosses Atlantic Ave from South Station to the One Financial Center block, and from the South Station across Summer Street to the Federal Reserve Bank building.
- South Station will be expanded to include MBTA parking facilities and potentially BRA mixed use development. The construction for MBTA parking facilities is estimated to begin in the Summer of 1991 and to take about two years. The slurry wall of this facility will be shared with the D011A contract.
- Bus layover activity currently occurring along Atlantic Ave will be relocated by the MBTA during their construction process.

2. The Leather District

- The area along the west side of Atlantic Ave. between Kneeland and Summer Streets is the border of the "Leather District". This historic district, comprised mostly of low rise brick structures, is listed in the National Historic Register. Some of the buildings have also been rated highly sensitive to construction impacts by the Project Conservator (see Conservator's Report of December, 1988).
- The buildings that border the Leather District along Atlantic Ave from Kneeland Street to Essex Street have numerous entrances and loading docks which are accessed directly from Atlantic Ave., including the following:

- * 210 South Street (Corner of Atlantic and Kneeland) has 3 loading docks and five service entrances
- * 745 Atlantic Ave has one loading entrance and one pedestrian entrance
- * 729 Atlantic Ave, Besco Sales Co. has one main pedestrian entrance
- * 727 Atlantic Ave has one main pedestrian entrance
- * 717 Atlantic Ave, the Fur Merchants Storage Co., has 2 loading docks and one main pedestrian entrance
- * 711 Atlantic Ave has one main pedestrian entrance
- * 695 Atlantic Ave (which houses the Essex Grill Restaurant and the Boston Health and Swim Club) has 2 main entrances and one secondary entrance.

2

3. One Financial Center

- At the corner of Atlantic Ave. and Summer Street is One Financial Center, one of the two high rise office buildings in the contract area. Entrances to both an underground garage and the building's loading docks are on the Essex Street side of the building.
- There is a pedestrian plaza in front of One Financial Center on the Atlantic and Summer Street sides. A fast food restaurant and a bank, among other shops, are on the ground floor. The offices, as well as this other activity, create an important pedestrian center.

4. Federal Reserve Bank Building

- The Federal Reserve Bank Building occupies the entire block between Summer Street and Congress Street along Atlantic Ave.
- Vehicular access to the building occurs along the Dorchester Ave. and Summer Street sides. The main pedestrian entrance to the building is off of Atlantic Ave on the Summer Street side.
- There is a landscaped area of grass and flowers in front of the building that is used as a park and place to eat lunch for office workers in the warmer weather. It is the only "green space" in the contract area.

6.2.2 Existing Conditions Inventory

An inventory of existing conditions will be completed in the Winter of 1991. Base maps indicating the following information will be provided to the SDC.

1. Vehicular Movement/Nodes (some traffic counts)
2. Pedestrian Movement (some pedestrian counts)
3. Building Uses and Entrances
4. Parking and Loading Zones
5. Historic Resources
6. Recreational/Tourist Uses
7. Other Construction Activity

6.3 Mitigation Requirements

Site-specific mitigation requirements are described below. Construction Impact Mitigation, found in Appendix A of this document, outlines the general mitigation guidelines the SDC must follow.

1. COORDINATION

There must be coordination of construction activity with other simultaneous construction projects. The timeframes and staging of these construction activities must be considered in order to minimize construction impacts to a given area. These activities include, but are not limited to, coordination with the following:

- * MBTA's South Station Transportation Center construction of shared slurry wall and parking facility, and Boston Redevelopment Authority development plans on same site
- * MBTA relocation of buses displaced by South Station construction, and later by CA/T construction.
- * Construction of MBTA's proposed future transitway
- * CA/T contracts D009A, D017A, D014A, D018A, D020B, and D022B
- * Summer and Congress Street Bridge construction schedules

2. TRAFFIC

The following lists traffic issues during construction in the D011A contract area to be specifically addressed in final design.

- * Provide two moving lanes of traffic one way on Atlantic Ave.
- * Provide two moving lanes of traffic on the Mass Pike off-ramp to Kneeland Street.
- * Provide local vehicular access to Beach, East, and Essex Streets (for those who live and work on the street) at all times.
- * Ensure through traffic in at least two of the following three Leather District cross streets at all times - Essex Street, East Street, and Beach Street.
- * If required, provide access to South Station Transportation Center garage access ramps at the Kneeland Street/Atlantic Avenue intersection.
- * Provide for taxicab service currently on the easterly side of Atlantic Avenue adjacent to the South Station building. Alternative locations include:
 - shifting taxicabs to west side, then back to east side
 - moving taxicabs to Essex Street
 - moving taxicabs to the south side of Summer Street

3. ACCESS

Construction must be staged in order to ensure pedestrian and/or vehicular access and flow to key locations at all times. These locations include, but are not limited to, the following:

- * heavy pedestrian traffic across Atlantic Ave between SSTC and One Financial Center, and across Summer Street from SSTC to the Federal Reserve Bank building.
- * delivery truck access to South Station
- * pedestrian access to South Station building via the main entrance at Dewey Square and via the entrance at the southerly end of the building on Atlantic Ave.
- * pedestrian and vehicular access to the Peter Pan Bus Terminal until such time as this facility is taken out of service.
- * pedestrian access to the Federal Reserve bank on the corner of Atlantic and Summer streets

- * pedestrian access to One Financial Center at Dewey Square

- * pedestrian flow across cross streets in Leather District, including Congress, Essex, East, Beach, and Kneeland

- * loading vehicle access to the buildings along the west side of Atlantic Ave between Kneeland Street and Essex Street (for listing of loading dock locations see Section 6.2.1 Leather District)

- * pedestrian access to the main entrances of these same buildings (listing of entrances can be found in Section 6.2.1 Leather District)

4. CONSTRUCTION PARKING AND VEHICULAR ROUTES

Specify construction worker parking restrictions in the bid package. CA/T staff are investigating remote area parking for construction workers, with shuttle/public transportation to work sites. The SDC should coordinate specifications with Project remote parking plans.

Specify routes and restrictions for construction vehicles and machinery. CA/T staff will be developing enforcement mechanisms to minimize traffic congestion and noise and vibration impacts. The SDC should coordinate development of specification with the enforcement mechanisms, as well as with adjacent construction contracts identified in Section 6.3.1.

5. PARKING

Delineate necessary lines of construction where parking will be taken, minimizing disruption and taking of existing spaces, and the amount of time they will be taken out of use.

- * street parking along west side of Atlantic Ave

- * street parking along the east and west sides of Atlantic Ave south of Summer Street

- * consider replacement parking locations for residential parking lost along the west side of Atlantic Ave between Beach and East streets

6. NOISE AND VIBRATION

Specify noise abatement measures including methods for support wall excavation, and work hour restrictions which will be used to accommodate the needs of these sensitive residential and/or business locations.

- * The Leather District businesses along Atlantic Avenue
- * One Financial Center
- * Federal Reserve Bank

7. HISTORIC AND OTHER SENSITIVE STRUCTURES

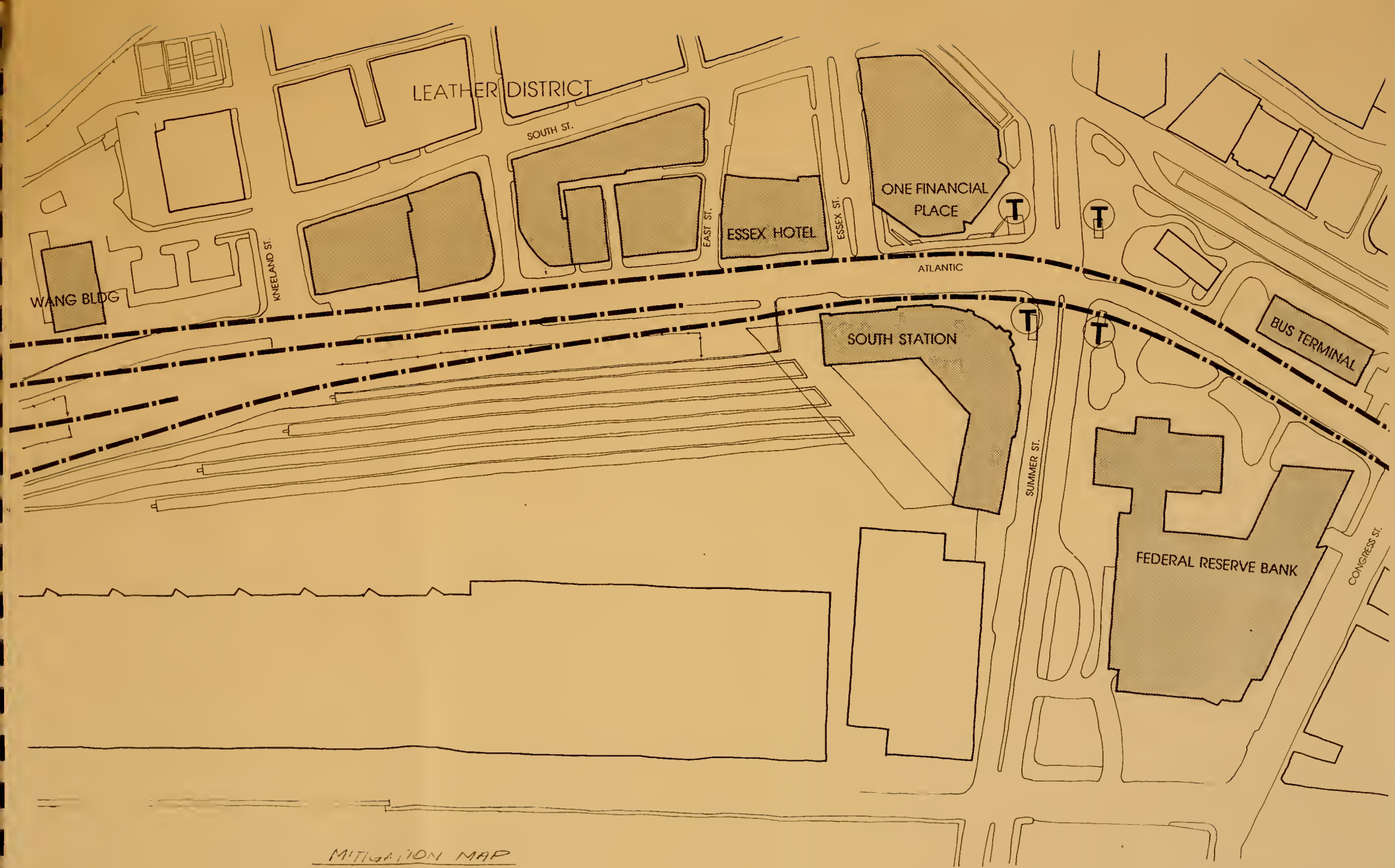
Specify methods which will be used to minimize construction impact to historic structures, and any other vulnerable structures in the D011A contract area which may require some form of special protection during construction. The SDC must determine what measures are necessary to protect adjacent buildings and convey this protection plan to the construction contractor via drawings and specifications in accordance with the requirements of Section 3.2.5 of the Scope of Services. The SDC shall base its determination on at least, but not limited to, the Conservator's Report (December, 1988), the Area Geotechnic Consultant's Report, and any additional studies required to ascertain structural stability.

- * Leather District buildings along Atlantic Ave. are on the Historic Register. Building protection may be necessary.

8. LANDSCAPING AND SURFACE RESTORATION

Minimize disruption and the taking of green space, trees and landscaping elements. (See Section 7.0 Landscape Architecture.) For landscaped areas which will be disturbed for a significant length of time before permanent restoration takes place, interim landscaping should be considered. These areas include, but are not limited to the following.

- * the pavement and landscaping in front of the Federal Reserve Bank



7.2 URBAN DESIGN

7.2.1 Existing Context

The western side of Atlantic Avenue running between Essex and Kneeland Street forms the boundary of the historic Leather District, which architecturally, has not changed significantly since the nineteenth century.

The buildings on this side of the street create a pleasant, continuous street wall composed largely of late Victorian brick buildings varying in height from 60 to 80 feet. The new building at 745 Atlantic Avenue follows the general pattern of unadorned brick facades that characterize the older buildings on the street. Several buildings are listed individually on the National Register of Historic Places, including the Fur Merchants' Warehouse, built in 1901 and the Plymouth Rock Building built in 1899, with a rusticated stone arcade and ornamented brick above. Rustication also characterizes much of the facade of the South Station Head House just opposite, built in 1898.

The street edge on the Leather District side of Atlantic Avenue is currently in very active use, housing a wide variety of commercial and professional offices interspersed with some modest wholesale and retail traders.

On the eastern side of Atlantic Avenue the platforms behind the South Station Head House were recently raised to facilitate at-grade boarding of Commuter Rail and AMTRAK trains. At the same time sub-grade foundations were installed to accommodate future air-rights development over the track area. The platform area is the primary access point for Commuter Rail and AMTRAK, and is the greatest single source of pedestrian activity during morning and evening rush hours.

7.2.2 Future Development

[New information on the BRA plan expected soon]

The construction of air rights development over the South Station tracks, including Greyhound and Trailways bus terminals will significantly increase pedestrian traffic in the area. With the exception of those destined for the Red Line, virtually all will need to cross Atlantic Avenue. The main entrance to the transportation related air rights development is opposite Beach Street.

The construction of the proposed Tufts International Research Center for biomedical and pharmaceutical research, occupying up to 1.5 million square feet, will also increase

pedestrian activity in the area. [Primary access to this facility is assumed to be opposite East Street but is not confirmed at this time].

7.2.3 Urban Design Concerns and Recommendations

Traffic signals are currently scheduled to be installed at Kneeland Street and Summer Street, similar to what exists today. It is important that the intersections of Beach St., East St., and Essex St. with Atlantic be reinforced visually as strongly as possible to alert drivers that they have left the highway and are entering a city street.

The sidewalk on the west side of Atlantic Ave. will be widened south of East Street to align with the curb in front of the Essex Hotel Building. This will result in a wider sidewalk to Kneeland St. Full advantage should be taken of this increase in width for tree planting along the curb side. Tree planting, similar to that currently proposed on the east side of the street, will help to reduce the apparent width of the roadway. Additionally, the use of neck downs to define parking zones and pedestrian crossings will help to reduce the apparent width.

Street furniture, other than roadway-related elements, should be sympathetic to the historic character of the Leather District.

While the seven existing loading docks between East and Kneeland Streets must stay in operation, their design should be at-grade with sidewalks as much as possible. The materials used in the loading areas should be part of the sidewalk although they may recall the historic uses of the area as loading bays for the Leather District.

Views along Atlantic Ave. looking toward the City do not focus on one particular building. As a driver proceeds toward Summer St. the view widens and will bring into view the proposed five-story Horticultural Center on Parcel 21.

7.3 HIGHWAY ARCHITECTURE

7.3.1 Portals

Portals

There are no portals to be designed in this contract. The I-93 NB portals at Kneeland Street and the ramp C Portal will be designed by the D009A SDC.

7.3.2 Tunnel Egress

7.3.2.1 Objectives

To provide for the life safety of tunnel occupants in the event of an incident within one of the tunnel bores, cross passages and egress stairs are being provided at regular intervals along the alignment. The approximate location of these elements is provided in the following sections. Criteria for egress design will be provided as a section of the Project Design Criteria.

7.3.2.1 Cross Passages

Cross passage locations were selected every 300' along the mainline bores, and within 300' along the ramp bores. Thus in D011A cross passages are located at approximately at the following stations, where 300 foot spacing was not possible, they were located in increments of 150'.

STA 87+00
90+50

7.3.2.2 Egress Stairs

Egress stair entrances have been located at alignment stations at which cross passageways are also located to maintain 300' spacing between egress points.

In general, the preferred location for egress stairwells is within gores or between adjacent bores rather than outside of the tunnel slurry walls. However, this approach has not been possible within the Contract D011A limits.

Potential stairwell locations were tested against the following constraints:

1. There must be less than 1000' between points of safety.
2. There must be space either within a gore, within the structure of the tunnel bores, or outside of the slurry wall, to locate a stairwell.

3. There must be at least one nearby open space at grade in which to locate the headhouse which does not conflict with the proposed surface street, urban design, or joint development plans.
4. There must be a clear vertical and/or horizontal path from the tunnel level to the headhouse site which does not conflict with the new utility locations.

Based on these criteria, the following approximate stairwell locations have been determined:

- Station 87+
- Station 92+
- Station 95+
- Station 101+

The stairwells are spaced substantially less than 1000' apart. This is due to the lack of an adjacent accessible bore for cross passages.

For each cross passage and stairwell, various incident locations were assumed, and the resultant egress load was calculated. The worst-case load was used to size the means of egress.

7.3.2.3 Egress Structures

The new emergency egress/access structures fall into four categories:

1. Headhouses adjacent to new ramp boat walls and exiting to the ramp walkway.
2. Headhouses located on parcels likely to be jointly developed in the future.
3. Headhouses located on parcels likely to remain undeveloped.
4. Headhouses developed in coordination with a MBTA subway exit headhouse.

Overall, the headhouse design shall identify the elements as part of the CA/T project by use of the same family of materials and forms as other CA/T architecture. At the same time, each headhouse must be successfully integrated with its immediate surroundings to minimize its physical presence.

In particular:

1. Headhouses adjacent to boat walls shall be fully integrated with the boatwalls both in form and material.
2. Headhouses located on parcels likely to be jointly developed shall be designed as freestanding elements which are likely to be fully subsumed or substantially altered by the future site development. During the interim period between project completion and joint development, they are likely to be the sole occupants of these sites.
3. Headhouses located on parcels likely to remain undeveloped shall be designed as permanent elements.

E. Interim Maintenance of Tunnel Egress

Cross-passages and egress structures are located per sections 7.3.2.1. and 7.3.2.2. of this report. Their locations assume a final construction condition in which both the I-93 North and South bound bores are operations. However, the I-93 North bound bore will be in operation prior to the opening of the I-93 South bound bore.

The Final Section Designer must review the construction sequence and staging for D011A, and must design temporary egress structures, landings, stairs, rails and any other associated life safety items for the interim use of the permanent cross-passages and stair egress structures. Egress from the I-93 North bound bore must be maintained prior to the opening of the South bound bore.

The evaluation and design of the interim egress facilities shall include but not be limited to:

1. Review of proposed construction sequencing and staging,
2. review of Project Design Criteria,
3. review of proposed permanent cross-passage and egress structure locations with regard to final surface conditions and interim surface conditions,
4. review of related final design contracts by others as referenced in Section 1.4 of the report,
5. review of existing artery and underpinning locations, and
6. review of temporary structures for traffic and pedestrian maintenance during construction.

The design of the interim egress facilities shall be in accordance with the Project Design Criteria.

7.3.3 Tunnel Finishes

The goals for the final design of the architectural finishes in the I-93 tunnel are as follows:

A. Driver safety and Orientation

Architectural finishes provide lane definition, assist in the legibility of signage, support rapid identification of cross passages/emergency exits and support the ambient light levels required for driver visibility. Graphics in the tunnel finishes will assist drivers in understanding their geographic location.

B. Ease of Maintenance

Architectural finishes should minimize facility and replacement costs. This will be accomplished by specifying appropriate materials which create surfaces that are easy to clean with standard tunnel wash equipment, and which resist corrosion related to entry of water into the finishes and connections.

C. Aesthetic

Architectural finishes provide a more pleasing aesthetic experience for drivers which in turn will provide the driver with a sense of security and confidence while driving through a restricted underground environment.

7.3.3.1 Wall Finishes

The wall finishes selected for the I-93 Central Area tunnel will be a non structural finish wall, consisting of structural glazed high density ceramic tile and tile set in cement mortar with grouted joints (consistent with Project Design Criteria, Section VI - Architectural Article 2.3.4 Tunnel Walls). Grout color should be selected such that the joints are not highlighted. Tile joints should be normal to the roadway. Allowance for expansion of the tile work should be provided 15' on center and whenever expansion joints in the structure are provided as a minimum. Wall panel shall be removable at standpipe locations.

Ventilation ports at side-exhausted tunnels are required. Spacing and size of ports are per D020B contract. This SDC shall coordinate ports for alignment to wall, ceilings, and graphic design.

Wall finish at portal flank walls is to be polymer concrete. Close coordination with the portal design is required.

The graphic design for the tunnel finishes will be developed by the D011A section design consultant and coordinated by this final section consultant along the following general guidelines:

1. Graphics are to be created by tile arrangement patterns, glazed tile surface patterns, or combination of both in conjunction with other tunnel finish elements. The size of the tile is to be determined by the Section Design Consultant in conjunction with the graphic design. Tile joints are to be normal to the roadway elevation.
2. Graphics are to be two-dimensional, and shall not cause protrusions from the wall finish surface nor create joints where corrosion might occur.
3. Graphic treatment on the walls of the tunnel should also reinforce lighting zones. The general design approach, including the colors to be used on the tunnel walls and ceilings, is provided in the Graphic Design Guidelines Manual, an appendix to the Architectural Design Criteria. Signage for

utility rooms, cross passages, egress stairs, colors, for standpipes, fire extinguishers, colors for handrails and any visible sign supports will also be specified in the Graphic Design Manual.

The SDC shall develop the graphic treatment in conjunction with the graphic design consultant.

7.3.3.2 Ceiling Finishes

The tunnel ceiling finish is to be concrete-filled porcelain enameled panels, as described in Article 2.3.3 Tunnel Ceiling Systems of the Project Design Criteria, Section VI - Architectural. The ceiling is suspended below the tunnel roof slab with a structural support system (see Structural Design) to form the tunnel exhaust air plenum. Corrosion protection of all metal, both exposed and concealed, must be addressed by the SDC. The ceiling will be installed horizontally when viewed in cross section rather than be superelevated with the roadway (see Preliminary Design Drawings). Gaskets shall be provided between panels to provide an air-tight seal for ceilings that serve to create the exhaust air plenum.

The ceiling panel design and configuration act to reinforce the spatial distinction between travel lanes and shoulder or gore areas in two ways. First, those panels located over the travel lanes shall be colored white, while those over shoulder areas shall be grey. Secondly, the grey panels shall be recessed in relation to the white panels. The transition between the tile wall finishes and the ceiling panels is to be accomplished by means of a flexible coved element. White panels shall continue into the portal facade to emphasize lane locations. The ceiling panels shall be removable and structural supports shall be detailed to provide for expansion and contraction due to temperature change. The cove panels shall be removable at Utility Room Locations from the roadway level.

Lighting Fixtures/Ceiling Panel Interface

Lighting fixtures are to be mounted in a continuous trough centered over lane markers in the tunnel. The trough is a corrosion protected steel channel into which the luminaire is inserted. The fastening of the trough to the ceilings and of the lights to the trough will be detailed to be corrosion-proof. Spacing of the

luminaires shall be as regular and uniform as possible. The spacings, numbers and locations of the fixtures are shown on the Electrical Directive Drawings.

A special lighting fixture is required to illuminate signs. This fixture will be attached to the ceiling system. All holes in ceiling panels are to be pre-punched before ceiling finish is applied. All lighting fixtures will be furnished and installed by others.

Signage/Ceiling Panel Interface

Roadway signs are supported by sign mounts which are in turn supported by the tunnel structure (see Section 5.0 Structural Design). The support structure requires provision of prefabricated openings in the ceiling panels, through which the sign mounts will hang. These directive openings are shown on Directive Drawing DD-H-002. The sizes and locations of these openings shall be coordinated with the D022A SDC. Sign alignment is parallel to the ceiling alignment.

Ventilation/Ceiling Panel Interface

Ventilation air ports will be fabricated into the ceiling panels (see Directive Drawing DD-H-001). These ports will be located and sized by the D020B SDC. The air ports will be fitted with an adjustable closure plate to control the opening size and consequent air exchange volumes. The closure plate will be coated with a corrosion protection material and mounted on the top surface of the ceiling panel. The fastening will be detailed to be corrosion-proof. The development of final details of the air ports will require close coordination with the D020B Section design Consultant.

Miscellaneous Interfaces

The Integrated Project Control System will require equipment such as Closed Circuit Television (CCTV), AM/FM Rebroadcast and linear thermal heat sensors. Embedments for equipment and their supports are the responsibility of the D011A SDC. Coordination with the D020B and D022A SDC will be required.

D011A SDC will coordinate with adjacent D017A SDC for all tunnel finishes.

7.3.3.3 Walkway Finishes

Tunnel walkway finishes are to be consistent with Article 2.3.5 Tunnel Walkways of the Project Design Criteria, Section VI - Architectural. These consist of facing panels of precast polymer concrete. Polymer concrete will extend to the transition walls of the portal facade. Three non-typical conditions exist, as follows:

1. The continuous linear recess above the curb on both sides of the roadway is interrupted at supply air port locations. The recess is to be dark in color to minimize the visibility of the flue locations as shown on the Architectural Standard Drawing SD-H-002.
2. At the tunnel portal where the walkway meets the roadway grade.
3. Non-typical panels exist where dimensions must be adjusted to respond to alignment curvature cross-over stairs or other dimensional variance. These panels will be sized according to unique dimensional requirements in each instance.

7.3.3.4 Roadway Level Doorways

Cross Passages

Cross passages connect separate tunnel bores and may be either within or independent of tunnel structural walls. The primary purpose is to provide an escape path from one bore to another. In some cases the cross passages may be combined with utility rooms and adequate space should be provided to accomplish both functions. Limited space for fire protection and communications equipment in the tunnel may be required in the tunnel. (See 11.0 Electrical Systems, and Section 12.0 Integrated Project Controls System (IPCS), and Sections 10.0 Mechanical Systems).

Materials and finishes are to be consistent with the Project Design Criteria, Section VI - Architectural, Article 2.8.5 Utility Rooms and Cross Passages.

Doors or pairs of doors will be operated with a sliding mechanism, since swinging doors could obstruct the walkways and impede emergency egress (approval of the Boston Fire Department will be required). Walls and doors shall be fire-rated.

Emergency egress signs shall be provided by the D011A SDC. Graphics associated with all rooms should convey their identification number and the availability of telephone, fire extinguisher or other life safety features. Design of graphics for signage is by others. Coordination will be required. The Section Design Consultant shall incorporate the approved graphic design concept into the design drawings.

Utility Rooms

At utility rooms, materials and finishes are to be as described for cross passages above. Panel walls are to be designed to support the equipment shown on the directive drawings. Equipment weights, dimensions, and connection details must be coordinated with the D020B and D022A Section Design Consultants.

Low Point Pump Stations

At low point pump stations (LPPS), the finish details are similar to those described above for the cross passage.

7.3.3.5 Handrails and Guardrails

All handrails must meet applicable dimensional and strength requirements. Guardrails will be provided at crossovers. Refer to Project Design Criteria.

7.3.3.6 Wall Cabinets

Wall Cabinets will be provided in the structural wall to accommodate fire extinguishers and standpipe hose valves. White porcelain enameled steel doors will be provided at each of these locations to protect this equipment from the tunnel environment. These doors are to be designed by the SDC. See H. Arch. DWG. DD-H-020 D020B Drawing SD-M-013.

7.3.4 Secondary Elements

Traffic signals, signage, fire protection, security, communications, and lighting are not in this contract; they are in the scope of Section Design Contract D022A. The location of sign supports will be coordinated in this contract. It is important that locations of sign supports be located within the dimensional framework of the tunnel architectural grid.

7.3.5 Construction Period Kit of Parts: Design and Use

A system of construction period elements has been designed to provide a "kit of parts" from which a variety of modular walkways, protective screens and supporting signage can be assembled to help mitigate pedestrian passage through construction zones.

The covered walkway system is protective, flexible, movable and durable and creates an environment which the user perceives as secure and comfortable. Design criteria for the walkways and associated elements are summarized in 7.3.5.1. Criteria governing the location and various applications of the kit-of-parts within or adjacent to construction zones are set out in 7.3.5.2 and illustrated below in Mitigation Drawings Nos. 1 and 2. The drawings illustrate the application of the kit-of-parts to slurry construction, decking construction and excavation mitigation.

Within the D011A area there are two major pedestrian crossings, one at Summer Street, linking commuters and others emerging from South Station and the bus terminal to the downtown and retail districts and one at Congress Street, linking the downtown area with the museums and parking on the South Boston side of Fort Point Channel. The Summer Street crossing will remain unaffected by construction. The crossing at Congress Street, however, will require continuous mitigation for the protection and preservation of pedestrian traffic.

Other existing pedestrian pathways across Atlantic Avenue include crossing at Beach Street and Essex Street. These must be maintained in a safe and usable manner at all times during the construction period.

Preliminary Design Drawings AR1-PD-L-204, 205 and 206 identify the locations of walkways and areas within D011A requiring some form of mitigation for pedestrians.

7.3.5.1 Kit of Parts: Modular System for pedestrian protection and information

A system of modular walkways, protective fencing and supporting signage can be assembled from a "kit of parts" to help mitigate pedestrian passage through and adjacent to construction zones. The interchange elements will be coordinated to create a visually integrated set of components which will be easily recognizable to pedestrians and drivers. The system includes:

1. Pedestrian covered walkway

A modular shelter based on a flexible system of elements will be used to provide overhead pedestrian protection from inclement weather and airborne construction debris. The shelter will be flexible, movable and durable as well as welcoming and reassuring to the public.

Each walkway shall be designed to:

- o have a typical clear internal section of 8'0" x 8'0" to accommodate three people travelling abreast (with two in wheelchairs); the minimum allowable width will be 6'0".
- o accommodate wall panels that are open to natural ventilation except where they must be solid for purposes of visual display or additional protection; solid panels must be painted in compliance with project-wide graphic standards; where used for protection, they must include glazed viewholes.
- o accommodate variably angled turnings (from 5 - 90 degrees) over its length while maintaining a continuous waterproof enclosure, a non-skid walking surface and maximum change in grade between walkway sections of 1/2 inch;
- o maintain an even walking surface; over areas with uneven ground conditions, walkway sections may be jacked or may sit on top of evenly spread levelling material;
- o accommodate continuous roofing for protection from weather, dust and debris; joints between walkway sections must be covered;
- o provide lighting at each 10 foot bay;

- o accommodate lateral openings along its length to permit access to shops or buildings where necessary;
- o be accessible to people with disabilities according to criteria set out by the Massachusetts Architectural Barriers Board, providing ramps with maximum slope of 1:12 to all walkways and maintaining them throughout the construction period;
- o incorporate sign bands inside walkway and on any visible exterior edge; project-wide graphics shall be applied to wall panels and roofing, as appropriate (see Project Graphic Design Manual, Appendix).

2. Gateway Structures

Covered walkways crossing the Artery corridor may incorporate gateway structures built by the contractor which flank the entries at both ends. These structures will have special graphic panels applied to them, designed by the SDC with reference to the Graphic Design Manual. For crossings of special significance [the Freedom Trail, Walk to the Sea, State Street], gateway design will draw on some aspect of local historical significance to create an appropriate sense of place for each location. Though the walkways at these major crossings may be relocated several times within a designated crossing zone, the gateway structures leading to them should be installed beyond the slurry walls at the edge of the construction zone so that they can remain in place throughout the construction period. For other cross-corridor walkways, gateway structures may either remain fixed or may move as the walkway itself is relocated. The height of gateway structures shall exceed the height of the covered walkway by a minimum of 1'6" and shall be located to be visible from a distance of 1/2 block. The gateway treatment must include colors and graphic elements common to the pedestrian protection and information system.

3. Information Kiosk

The kiosk will incorporate project-wide graphics which will supply way-finding assistance at or near the entrances to covered walkways.

4. Construction Barricade

The barricade will consist of a jersey barrier base with panels above. A sign band displaying project-wide graphics will be affixed at the standard height above the panels.

5. Construction Fencing

Fencing will be chain link with a sign band at the standard height used for the covered walkway, information kiosk and construction barricade.

6. Planters, trash barrel, and pedestrian crossing beacon

These will be manufactured products which will be visually linked to the kit of parts imagery through the use of project-wide graphics. A minimum of two trash barrels will be used at the entrances to each covered walkway. Planters shall be used outside of the construction zone to screen construction activity and fencing and to strengthen pedestrian awareness of gateway locations.

Kit of parts layouts shall be site-specific and designed by the final designer to follow construction phasing plans. Elements from the kit may be used for additional project-related purposes not specified here, eg., to provide covered shelters for tour bus operations.

7.3.5.2 Construction Kit of Parts: Criteria for Use

Mitigation measures must provide for the comfort and convenience of both drivers and pedestrians travelling through or near construction activity. Two northbound lanes of surface traffic flanking construction zones must be maintained throughout all construction stages. Safe crossings must also be maintained on surrounding local streets directly affected by construction activity.

The following guidelines set parameters for the location of walkways and other kit-of-part components:

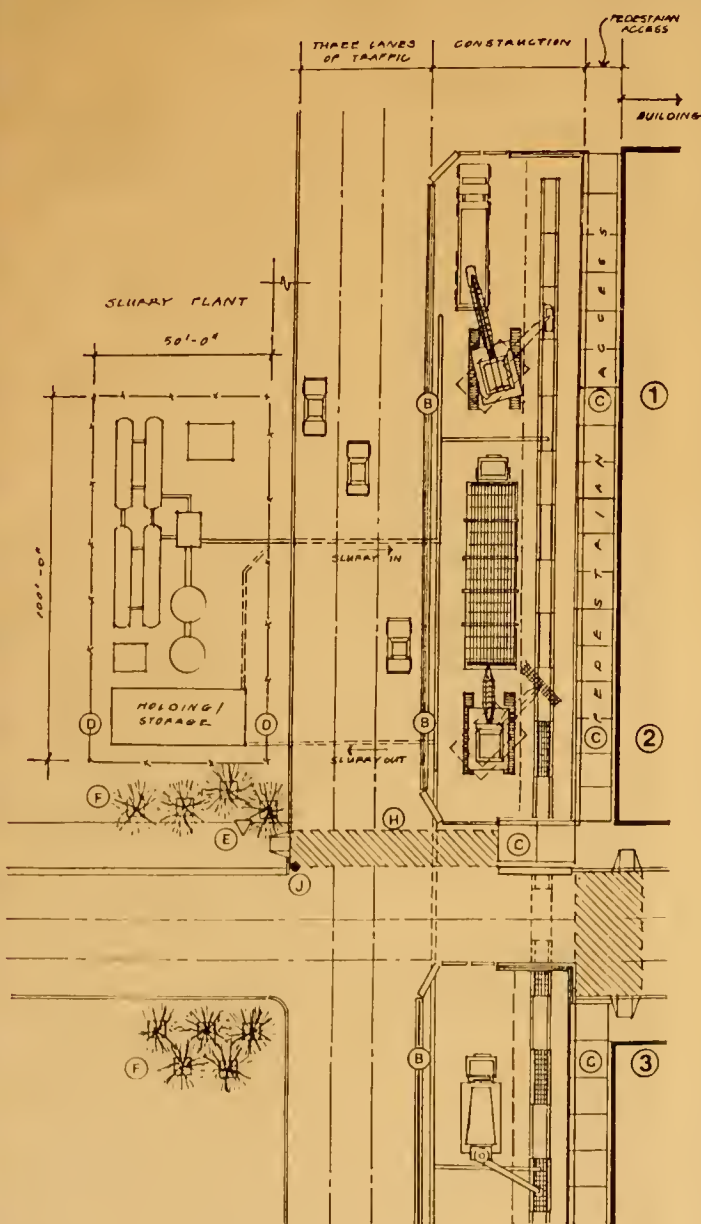
1. Construction zones shall be separated from public access by continuous fencing and construction barricades, interrupted only by removable barriers used to allow the ingress and egress of equipment and construction materials.

2. For additional protection, temporary roadway protection shall be applied along the length of the site perimeter corresponding to the section of slurry wall under construction at any one time; this shall be moved along the perimeter, following the course of slurry wall activity. Where covering is required, it must be compatible with design and maintenance standards specified in DD-H-401, 402.
3. Established pedestrian crossings shall be maintained throughout all construction stages and shall be separated from vehicular traffic.
4. The covered walkway will be employed at all times except when it is interrupted for the passage of traffic where safety striping and ramps will be provided. Walkways may be covered or uncovered, depending on their proximity to construction activity and the specific circumstances of each location.
5. Wherever possible, these walkways will maintain their existing width; where reduced by construction demands, a minimum allowable width of 6'0" shall be maintained.
6. Where walkways disgorge pedestrians into vehicular traffic, traffic signalling, lighting, safety striping on pavement or decking and pedestrian crossing beacons at each end of the walkway shall be provided to ensure safe passage in compliance with city requirements.
7. Where walkways begin or end at a mid-block location, provision must be made to guarantee wheelchair access, in compliance with state accessibility requirements for a corner location.
8. Where the boundary of construction activity occurs within 5' of an existing sidewalk or temporary pedestrian route, the pedestrian zone will be separated from construction activity by a continuous barrier and/or protective fencing (see DD-H-406, 407) for protection measures required by specific building operations).
9. Where moving traffic runs alongside pedestrian access and a curb no longer exists to separate them, a continuous jersey barrier will be used to distinguish the pedestrian zone from the vehicular zone.

10. Site perimeter fencing will sit between 10' - 12' beyond slurry wall activity. Where it is not possible to maintain a minimum (6'0") walkway width, pedestrian traffic must be rerouted; where necessary, protected pedestrian passageways shall be provided along the opposite flank of the construction zone, running parallel and adjacent to the north-south vehicular traffic. These walkways will be separated from the construction zone and from traffic by construction barricades or covered walkway sections. Information kiosks including site maps and directional signage shall occur wherever the existing path is disrupted.
11. Where there is a choice of location between two sides of an intersection, walkway shall be located on the side with the greater volume of pedestrian traffic.

Maintenance Provisions

Throughout the construction period, walkways must be properly maintained, kept lit, clean, dry, clear of snow and ice, painted; signage must remain legible and accurate as walkway changes location. This will be the responsibility of the contractor.



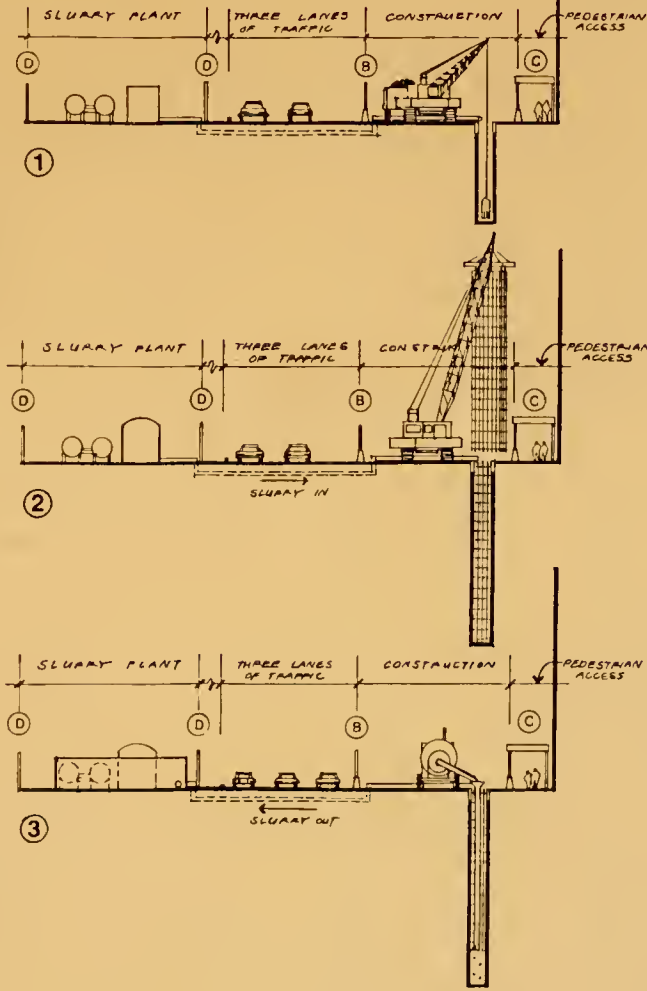
SLURRY WALL CONSTRUCTION
PROTOTYPICAL CONDITIONS/PLAN

The construction zone, 30' to 40' wide, will be separated from public access by a continuous concrete barrier broken only by removable wooden barriers used for construction vehicle ingress and egress. When required for public safety, construction operation protection or dust and debris containment, a 6'-10' high fence will be erected to the concrete barrier. Safe pedestrian access and three lanes of moving vehicular traffic (in each direction, north and south) will be maintained throughout all of the construction stages. Pedestrian and/or vehicular crossings through construction zones (east and west, perpendicular to Central Artery corridor) will be provided within designated zones.

The proposed slurry wall location will be surveyed and staked. Guide wells will be placed on either side of the proposed slurry wall alignment. A crane equipped with a clam shell bucket will excavate alternating sections, approximately 15' long, between the guide wells. Materials from the 50'-100' deep trench will be loaded onto dump trucks and carried to the barge loading facility, treatment plant or land fill site.

Bentonite slurry, piped from an on-site slurry plant, will fill the trenches and stabilize the trench walls. Steel reinforcing cages will be lifted and placed into the slurry-filled trench by a crane.

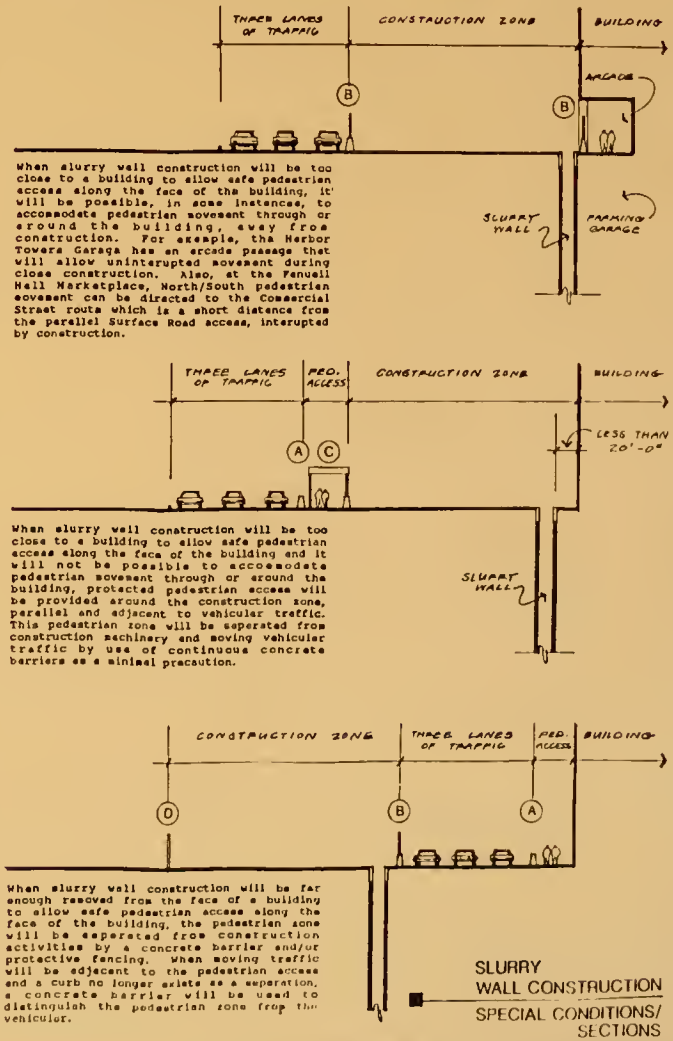
Concrete, delivered to the site in transit mixer trucks, will be placed into the bottom of the trench by use of a hopper and tremie pipe. As the concrete fills the trench, the bentonite slurry will be displaced and will be pumped back to the slurry plant where it will be held in storage and reprocessed for future use. As the concrete-filled trenches cure, the entire process will be repeated for the alternating 15' sections between the completed concrete wall sections. For the length of one city block, approximately 250 feet, and assuming a 100 foot depth, a duration of 5-6 weeks should be expected for completion of one continuous slurry wall.



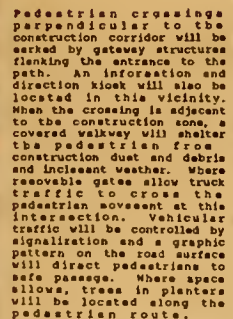
SLURRY WALL CONSTRUCTION
PROTOTYPICAL CONDITIONS/SECTION

KEY: KIT-OF-PARTS

- | | |
|---------------------------------|----------|
| (A) CONCRETE TRAFFIC BARRIER | DETAIL 7 |
| (B) CONSTRUCTION BARRIER | 80-H-403 |
| (C) PEDESTRIAN COVERED WALKWAY | DETAIL 1 |
| (D) CONSTRUCTION FENCE | 80-H-403 |
| (E) INFORMATION/DIRECTION KIOSK | DETAIL 4 |
| (F) FIBERGLASS PLANTER | 80-H-403 |
| (G) GATEWAY STRUCTURE | DETAIL 5 |
| (H) SAFETY STRIPING | 80-H-403 |
| (J) CROSSING BEACON | DETAIL 3 |
| | 80-H-403 |



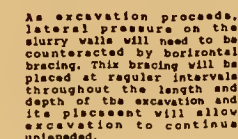
SLURRY WALL CONSTRUCTION
SPECIAL CONDITIONS/SECTIONS



- ① In order to shorten the bress span between slurry walls, temporary pins or post piles will be placed approximately 10' on center in a line parallel to the slurry walls. Holes for the piling will be drilled to a depth equal to the slurry wall depth. After the piling are placed, they will be connected by a bress set on top of the pile.
- ② The area between the slurry wall and the pin or post pile bress will be dug out to receive the deck bress. A backhoe excavator will be used to remove the excavated material and load it into a dump truck, which will carry the materials to the barge loading facility, treatment plant or land fill site.
- ③ A crane will lift the deck bress from the bed of the delivery truck and place it to bear on the slurry wall and pin or post pile bress.
- ④ Further excavation between deck bress and around existing utilities will then be done. Because of the fragility of many utility structures, each of the excavation will need to be done by hand. Utilities will remain in the location in which they are found. Some existing services may be relocated to accommodate excavation.
- ⑤ Planking panels (wood or concrete) prefabricated to specifications that accommodate the span between the deck bress, will be lifted from the delivery truck bed and put into place by a crane. Panels will be approximately 4'-0" wide, 10'-0" long and 12" thick.
- ⑥ Once the panels are in place, the utilities will be suspended from the deck bress at all in their original locations, vertically and horizontally. Material beneath the utilities will then be carefully removed.
- ⑦ When the decking procedure has been completed, vehicular traffic can then move to the decked area. The entire procedure will then be repeated until the area between two slurry walls is completely covered and excavations can continue beneath the decking.

DECKING CONSTRUCTION
PROTOTYPICAL CONDITIONS/SECTION

(A)	CONCRETE TRAFFIC BARRIER	DETAIL SD-H-403
(B)	CONSTRUCTION BARRIER	DETAIL SD-H-403
(C)	PEDESTRIAN COVERED WALKWAY	DETAIL SD-H-403
(D)	CONSTRUCTION FENCE	DETAIL SD-H-403
(E)	INFORMATION/DIRECTION KIOSK	DETAIL SD-H-403
(F)	FIBERGLASS PLANTER	DETAIL SD-H-403
(G)	GATEWAY STRUCTURE	DETAIL SD-H-403
(H)	SAFETY STRIPING	DETAIL SD-H-403
(J)	CROSSING BEACON	DETAIL SD-H-403

EXCAVATION PROCEDURE
 PROTOTYPICAL CONDITIONS/SECTION

7.4 LANDSCAPE ARCHITECTURE

7.4.1 Introduction

The scope of Landscape Architecture in this section design contract includes design for two time periods:

- A. Construction period pedestrian enhancement and protection;
- B. Final surface restoration including restoration of the sites on parcels, sidewalks, streets, and medians which lie above or adjacent to the new tunnels. This will be the condition in which the surface is left at the conclusion of the D011A contract.

7.4.2 Construction Period Pedestrian Protection

Pedestrian areas within D011A are very active and often crowded, reflecting their proximity to major transportation centers. Throughout this area, the SDC shall provide a safe, clean, and unencumbered pedestrian environment during the construction period. This protection is to be accomplished for mitigating to the extent possible the negative effects of construction activity, and by providing continuous, direct, and protected pedestrian walkways and crossings throughout the contract limits.

Pedestrian corridors across the construction site shall afford protection from the high winds which characterize the site due to the position of several tall buildings in an area of either open streets or low to mid rise buildings.

In the case of Atlantic Avenue between Kneeland and Summer Streets, there shall be sheltered and protected sidewalks bridging the tunnel construction area at East Street, Essex Street and Beach Street. There will also be a covered walkway along Atlantic Avenue adjacent to the west wall of South Station.

Construction period furniture and pedestrian enhancements such as lighting, canopies, color, and signage will promote a positive, human image of the project, and will encourage the passing public to observe and become involved in the construction activity by posting information relevant to visible construction activities.

Construction period information will also include interpretive signage and elements calling attention to the "Leather District" as well as to other places of historic interest in the D011A project area.

Special signage, acoustical devices and provision for access shall be provided for handicapped and the visually impaired at all major construction period street crossings.

Pedestrian travel is to be maintained as close to normal routes as possible, with minimal interruption, throughout the construction area and time period. Access to existing businesses, to the South Station's principal public entrances, and to historic attractions has the highest priority, particularly for tourists who arrive and depart from the proposed Transportation Center. Extremely high pedestrian crossing activity is characteristic of the corner of Atlantic and Summer Streets and at Essex and East Streets crossing Atlantic Avenue.

See Section 7.3.5 for the design and use of temporary structures to accommodate pedestrian traffic during the construction period.

7.4.3 Final Surface Restoration

General

Primary areas of landscape design restoration in D011A include the Atlantic Avenue streetscape and special pedestrian treatments related to the high volume of activity around South Station, the streetscape transitions into the Leather District streets which meet Atlantic Avenue and the restoration of sites involved in the tunnel construction at Dewey Square, One Financial Center, and the Federal Reserve. Design issues will include development of historic interpretation and historic district definition utilizing streetscape materials.

Planting

In the transitional area between D011A, D009A and the South Bay Interchange, the land available for planting shall be used to develop a gradual shift in the character of tree planting from the infield in D009A to the more formal and closely spaced tree planting characteristic Atlantic Avenue.

Within the street corridor between Kneeland and Summer Streets, the formal pattern of tree planting interposed between lighting that is characteristic over the length of the Surface Central Artery shall be employed where possible to create a consistent edge along both sides of the street.

An exception to the above shall be employed where the facade, loading bays, or other distinctive entrance features of buildings in the National Register Leather District can be exposed to passing traffic. In these cases, the formal tree

planting shall be left out to best expose desired features to the public view. Unless they are part of the building's major entrance design, the remaining building facade shall be fronted by the theme street tree planting.

On the east side of Atlantic Avenue planting will need to be consistent with the lighting and tree layout pattern on the west side as well as being coordinated with the proposed Transportation Center.

Sidewalk Paving and Grading

Sidewalks should have a consistent detailing and paving material and curbing throughout the surface restoration corridor. When sidewalks are to become widened, the grading of the walks from building face (bottom of wall) to curb should be sloped consistently. Where slopes away from the building are minimal, the curb and hence the roadway grade, should be lowered in order to allow a minimum 1% pitch and to avoid the necessity of a swale or drain within the sidewalk. The surface at loading docks should be flush with sidewalk paving wherever possible. The vehicular ramp required should be sloped at no greater than 8%.

In many areas, special paving of historic importance exists and should be protected and retained or re-installed. This includes the large granite paving slab at the Tufts Building between Congress and Purchase Streets.

Crosswalks

Where there are signalized intersections or the likelihood of high volume pedestrian crossings, crosswalks of full-depth stone or masonry material in a concrete base shall be used. Material installed should have a smooth and durable surface.

Cross Street Development

In contradiction to a consistent treatment of the streetscape along the Central Area surface artery, the cross streets shall be designed to call attention to unique or historic conditions appearing in the vicinity of the crossing. The location of planting, lighting design, the paving materials, and other details which in some way reinforce conditions observed along the cross streets shall all be used to assure the surface artery does not visually divide the existing urban district. These cross-streets in D011A include only Summer Street and Congress Street.

Lighting

Street lighting throughout the surface area restoration should be consistent. Intersections should have increased lighting on the street. Pedestrian lighting should also adhere to the surface artery standard; however, the sections of the streets crossing the surface artery should feature lighting consistent with the present cross street to reinforce continuity.

Pedestrian Furniture

Streetscape elements for pedestrians should include a system of benches, trash receptacles, historic markers, pedestrian signs, bollards, and seat walls which are consistent throughout the surface artery. The exception shall be in the use of contradictory elements at the cross streets when clear reference to the historic or unique materials and furnishings of the cross streets shall be expressed in ways in which they can be used and seen as part of the street.

7.4.4 Plant Material

Plant materials will be deciduous trees in moveable planters, species suggested include;

- o Tilia cordata - Littleleaf Linden
- o Gleditsia Triancanthos Inermis - Thornless Honeylocust
- o Acer Platanoides - Condon Plane Tree

8.0 Surface Drainage

8.1 Existing Congress Street Pumping Station

The Congress Street pumping station is presently located in the easterly wall of the Dewey Square Tunnel, directly under the Atlantic Avenue, Congress Street intersection. This pumping station collects surface drainage from the existing Central Artery Northbound and Southbound roadway from approximately Oliver Street to the tunnel portal, and from ramps RR, RQ, RS and RT, and the tunnel drainage for approximately half the Dewey Square Tunnel.

The westerly slurry wall of Design Contract D011A slices through the existing Congress Street pumping station. Therefore, this contract will include the redesign and construction of a temporary pumping station, utilizing the remaining portion of the existing pump station and equipment, to service the area presently serviced by the existing pumping station.

8.2 New Surface Drainage

The D011A new surface drainage is divided into two sections, the northern and southern portion.

The MBTA South Station subway station acts as a barricade preventing a continuous gravity drainage system.

The northern portion will be a gravity system which will collect the surface drainage from Atlantic Avenue., between Summer Street and Congress Street. The discharge will be to the Fort Point Channel through an existing 48" storm drain sewer which runs along Congress Street from Atlantic Avenue to the Fort Point Channel.

This system represents the replacement of an existing storm drain system which has been dislocated because of mainline construction.

This system will also receive the discharge from a MDPW owned Storm Drain Pumping Station for proposed ramp RT portal section only. Ramp RT portal is located outside this design contract limits, but its pump discharge force main will be routed to a storm drain manhole at the intersection of Atlantic Avenue and Summer Street. Flow quantity is minimal.

The southern portion will be a gravity system which will collect the surface drainage from Atlantic Avenue, between Summer Street and Kneeland Street and discharge it into a MDPW owned pumping station no. 09A-SW-02, located in the South Bay Interchange.

Pumping station no. 09A-SW-02 will also receive the surface drainage from Ramp C portal, the C.A.N.B. portal and portions of the South Bay Interchange.

This pumping station is part of Design Contract D009A. If this pump station is not ready by the time it is needed to receive the drainage flows from Atlantic Avenue, (D011A), then the Atlantic Avenue drainage will have to be temporarily outlet to the 81" X 81" C.S. Crossing Atlantic Avenue at Kneeland Street.

9.0 Utility Relocations

9.1 Utility Relocation Corridors

Utility Relocations corridors for Design contract D011A consists of a longitudinal corridor for the entire length of contract limits with tie ins at Congress Street, Summer Street, and a transverse corridor at Kneeland Street.

Due to the limited available space outside the slurry walls, these corridors all fall within slurry wall limits.

Design Contract D011A is an all inclusive contract incorporating utility relocation, mainline construction and surface restoration into one cooperative effort.

Two utility services within this corridor which can not be interrupted for any period of time are the New East Interceptor (NESI), combined sewer and the steam main.

NESI is a 72 "combined sewer which services the financial and business districts of downtown Boston. It has a continuous flow and can not be interrupted.

The existing 16" steam line and or the proposed 24" steam line and 8" condensate return will be one of Boston Thermal Energy Corporation's (BTEC) main supply for its east distribution network located in downtown Boston. This line is in constant operation year round except for two - two week maintenance shut downs, one early spring and one in early fall.

Noting these factors, the new utility systems and other utilities should be designed, installed and supported from the slurry walls before main line construction.

The utility support system shall be designed to avoid any settlement, minimize any vibration being transferred to the utilities and consider all resultant and expansive forces generated from pressurized systems.

Refer to Section 5.0 for the structural requirements of the utility system.

Provisions also should be made to:

- o Adequately protect all utilities during construction,
- o Provide personnel protection for electrical and steam conduits and manholes
- o Provide freeze protection to all susceptible utilities,
- o Maintain waterproofing to all electrical and communication conduits and appurtenances. Electric, communication and steam conduits have not been concrete encased within this corridor in order to minimize dead loads,
- o Maintain access to all manholes and valving.

Upon completion of the mainline tunnel construction, and during the backfilling process, all utilities are to be properly reset upon properly compacted backfill material.

Due to the difficulty of properly compacting backfill under utilities, and the removal of undercarriage steel without disrupting the utility, a lean concrete cradle will be considered between the utility and the properly compacted backfill.

This concrete cradle will be poured around the undercarriage steel. When the concrete has cured, the tie rod supports will be removed.

Also, electrical, telephone, other communication conduits and steam line conduits are to be concrete encased in accordance to owners specifications.

During the preliminary design phase, numerous meetings were held between the Management consultant and the utility agencies/companies, including:

- * Boston Water and Sewer Commission
- * Boston Edison Company
- * New England Telephone Company
- * Boston Gas Company
- * Boston Thermal Energy Corporation

Continued design coordination between the SDC and the above agencies/companies is required during the final design process.

Coordination and communication with other agencies during the final design process is also required. These include, but are not limited to, the following:

1. MBTA

Coordination with the proposed transit way, South Station Subway Station construction project, and the design of the AC and DC electric conduits along Atlantic Avenue between Congress St. and Essex St.

2. Boston Transportation Department

Traffic detours during construction, construction vehicle routing and scheduling, parking impacts, traffic signal timing and phasing during construction.

3. City of Boston Public Works Department

Pavement, sidewalk and planting area restoration requirements, street openings, site drainage, curb cuts, temporary pavements, pedestrian walkways.

4. MDPW

Traffic relocation, pavement restoration, maintenance of pedestrian accessways.

5. MWRA

Regulatory control on outfall structures and other services.

9.2 Major Utility Relocation Summary

The following is a summary of the major utilities which will be designed, constructed and supported as part of Design Contract D011A.

- o Combined Sewer
- o Water
- o Gas
- o Steam
- o Fuel Oil
- o Electric
- o Telephone

Combined Sewer

This contract will include design and construction of a 72" reinforced concrete sewer pipe to be designated as the new relocated N.E.S.I.

The new relocated N.E.S.I. will be a continuation of N.E.S.I from Design Contract D017A. Interface will be at Atlantic Ave., at the intersection of Congress St.

Termination will be at the existing N.E.S.I. 72" on the north west side of the intersection of Atlantic Ave. and Summer St., just before the M.B.T.A. South Station Subway Station.

This contract will also include the design and construction of a combined sewer, varying in size, from Beach St. and Atlantic Ave., sloping toward and discharging into an existing combined sewer regulator structure at the intersection of Atlantic Ave. and

Summer St. This sewer will collect the wet weather flow from the existing combined sewers at Beach and East Streets, and the entire flow from the existing 36"x54" combined sewer located on Essex St.

Finally this contract will include the design and construction of a combined sewer diversion structure at the intersection of Atlantic Ave. and Kneeland St.

Presently at Atlantic Ave. and Kneeland St., there is an existing regulator structure which collects the flow from two combined sewers, one 68"x102" and one 30"x36".

Dry weather flow from these two combined sewers is diverted to the existing N.E.S.I. located in Atlantic Ave.

Wet weather flow is diverted to an 81"x81" CSO which crosses Atlantic Ave. and railroad property and eventually discharges into the Fort Point Channel.

The adjacent N.E.S.I. relocation design contract, (D014A) will divert the dry weather flow from the two existing combined sewers back to the new relocated N.E.S.I.

D011A design contract will include the design and construction of a regulator structure which will collect the wet weather flows from the two existing combined sewers, and divert them by a properly sized and located sewer, across Atlantic Ave. to the existing 81"x81" C.S.O.

The design of the sewer connecting the new regulator structure and the existing 81" x 81" CSO must take into consideration the limitations of this area. Kneeland Street at Atlantic Ave. is very close to the CANB portal, and the mainline tunnel roof structure is very close to grade. This intersection is also host to the 24" steam and 8" condensate return lines which traverse Atlantic Ave. and head westerly on Kneeland St. to the Boston Thermal Energy Corporation Steam Station.

Water

This contract will include the design and construction of 3 separate water lines, (16" Low Service, 12 High Service and 16" High Fire Service) for the entire length of contract limits.

Each water service will have a valved junction connection to each existing system at each roadway intersection.

Gas

This contract will include the design and construction of a 6" low pressure gas line in Atlantic Ave. from Kneeland St. to Essex St. An existing 30" intermediate pressure gas line located in Atlantic Ave. has previously been relocated out of the construction area, under a separate contract.

Steam

This contract will include design and construction of a 24" steam line and a 8" condensate line and all necessary appurtenances from BTEC's Kneeland Street Steam Station, along Atlantic Ave. to the contracts northern limit at Congress St.

Fuel Oil

This contract will include the design and construction of a 4" fuel oil line from BTEC's Kneeland Street Stream Station, along Atlantic to Summer Street where it will reconnect to the existing 4" fuel oil line on Summer St.

Attention is called to the fact that the fuel oil will remain viscous during cold weather periods. Insulation or heat tracing should be considered for exposed piping.

Electric

This contract will include the design and construction of new electric conduits for Boston Edison and the M.B.T.A.

Boston Edison has requested 2 banks of 9-5" conduits each to run in Atlantic Ave. from Kneeland Street to Congress St. Each bank is to be designated "E (9-5)".

Electric manholes for each conduit bank will be required at Kneeland, Beach, Essex, Summer and Congress Streets in order to make connections to the existing network.

The MBTA has requested 2 banks of conduits to be extended from their Design Contract D017A termination point to new manhole structures at the intersection of Atlantic Ave. and Summer St., at which point they will be reconnected to the existing network.

One bank of conduits consists of 14 conduits of 4" diameter which will be designated "DC(14-4)".

The other bank of conduits consists of 10 conduits of 4 inch diameter which will be designated, "AC(10-4)".

Telephone

The New England Telephone Co. has requested a bank of 20-4" diameter conduits to be extended from their Design Contract D017A termination point to a new manhole at the intersection of Atlantic Ave. and Summer St., at which point they will be reconnected to the existing network. This bank will be designated "T (20-4)".

In the southern portion of this contract, Summer St. to Kneeland St.) there are two small banks of telephone conduits which are in conflict with slurry wall construction.

One bank consists of four 3" conducts running from Kneeland St. to Beach St. The other bank consists of two 3 conduits running from East St. to Essex St.

Because of the relative small size of these two banks of conduits, consideration should be given to relocating them outside the slurry wall in order to avoid support requirements.

DESIGN CONSIDERATIONS

The design within this utility corridor will have to take into consideration the proposed M.B.T.A. "People Mover" project.

The MBTA is proposing to construct a transit way system over the mainline tunnel from Essex Street to Congress Street.

An enlargement of the existing M.B.T.A. South Station subway station is also proposed in conjunction with this project in order to facilitate transferring between transit lines. The exact location and sizing of the station is unknown at present.

A 32 foot wide by 22 foot high corridor on the east side of the main line tunnel roof has been reserved for the transitway.

Preferred location for N.E.S.I. would be to the west of this reserved corridor.

All other utilities should be located on top of or adjacent to this corridor, but not within.

9.2 Minor Utilities and Service Connections

This Contract will include the design, support, and protection to all minor utilities and service connections slated to remain in service during and after construction.

Final Design Drawings shall incorporate all smaller utilities and service connections designated to be relocated, replaced or eliminated and a sequencing of construction in order to minimize disruption of service.

Public and private agencies that may have utility services within the construction area, which will need protection from damage and, if necessary, temporary or permanent relocations, are:

- o Massachusetts Department of Public Works
- o Massachusetts Water Resources Authority
- o Metropolitan District Commission
City of Boston (Police, Fire, Transportation,
and Lighting Departments)
- o Boston Thermal Energy Corporation
- o Western Union
- o Sprint
- o MCI
- o McCourt
- o Teleport
- o Cablevision of Boston

Design effort shall also include all temporary facilities required to insure pedestrian safety and to maintain vehicular traffic flow.

Street lighting and other exterior lighting is an important safety issue during construction, and will remain in service or be relocated. Traffic signalling, temporary or permanent, shall be coordinated with MDPW, Boston traffic and other involved agencies in conjunction with section 6.0.

10.0 Mechanical Systems

10.1 General

The I-93 Northbound Atlantic Avenue Tunnel(D011A) Section Design Consultant(SDC) will be required to incorporate into the design, certain systemwide mechanical elements to be designed by the I-93 Mechanical/Electrical Systems(D020B) SDC which generally include embedded piping, fire standpipes, the structural formation of the tunnel ventilation air ducts, transitions, flues, ports, and damper openings.

Directive Drawings have been prepared to identify how these systemwide mechanical elements integrate with the structural design of the tunnel sections. Preliminary engineering has been performed to establish approximate equipment sizes, duct dimensions, flue and port quantities and spacing, pipe sizes, drainage requirements and to functionally coordinate and facilitate the arrangement and orientation of these elements with other systemwide elements and structural requirements.

The D020B SDC will be responsible for establishing the final design requirements for the tunnel ventilation, tunnel drainage and roadway fire protection systems including those elements requiring incorporation within the tunnel sections. The D020B SDC will also provide Directive Drawing verification, technical guidance and general coordination of these elements which affect the design work of the I-93 Northbound Atlantic Avenue Tunnel Section Design Consultant.

10.2 Tunnel Ventilation

Ventilation within the I-93 Central Artery tunnels beneath Atlantic Avenue between Kneeland and Congress Streets and their associated ramps will be provided as part of a multi-zone full transverse ventilation system. Ventilation Building No. 3 will house the fourteen exhaust and nine supply fans which are required to provide the

necessary amounts of supply and exhaust air to these tunnel sections and associated ramps.

With this type of ventilation system, fresh air is supplied via continuous ducts located beneath each mainline tunnel roadway and associated ramps. These ducts will be formed as part of the tunnel structure. The fresh air is delivered at curb level, along both sides of the roadway, through a series of embedded flues placed at predetermined intervals for the entire length of the tunnel. Exhaust air is collected through ports in the ceiling and transported back to the ventilation buildings via a continuous duct which is formed above each mainline roadway and associated ramps between the underside of the tunnel roof slab and the finished ceiling.

Preliminary engineering has been performed to estimate the minimum duct cross-sectional area required for exhaust and supply air so as not to exceed the maximum allowable air velocities in the ducts. Since lower velocities are preferable, the design of the exhaust air ducts shall make maximum utilization of the available space above and below the roadways by providing as large a cross-sectional duct area as is physically possible within the structure. Due to varying widths of the tunnel roadways and the need to dispense supply air from each walkway, two supply air ducts are provided under each mainline roadway in order to efficiently connect flues to each curb.

The mechanical Directive Drawings reflect the preliminary engineering of those elements of the ventilation system which affect final design of the I-93 Atlantic Avenue Tunnel structure; these include supply air duct cross-sectional area, and supply air flue geometry and spacing. Verification of this information will be performed by the D020B SDC who is responsible for the final design of the ventilation system.

10.3 Tunnel Drainage

A drainage system will be included within the I-93 Atlantic Avenue Tunnel and associated ramps. This drainage system is distinct from the storm drainage system and from the stormwater pump stations which are designed to collect run-off in the tunnel approaches adjacent to the portals and to prevent stormwater from entering the tunnel at the portals.

For the purposes of design, it has been assumed that during a 50-year storm event, a certain amount of run-off will by-pass the transverse storm drain at the portal(s) and thus contribute influent to the tunnel drainage system. Another major contributor considered in the

preliminary design of the tunnel drainage system is the amount of water resulting from fighting an in-tunnel fire.

Although there are other contributors to the tunnel drainage system such as vehicle drippings, structure seepage and ventilation duct drainage, these are all assumed to be negligible and considered to have no effect on the system's capacity. Preliminary calculations of inflow resulting from tunnel wash down operations indicate that this flow would be less than that of a fire fighting operation.

The tunnel drainage system, as described in "Tunnel Drainage Concept Report," consists of an embedded gravity drain pipe running longitudinally below the curb on the low side of each super-elevated roadway which will collect the drainage water through inlets spaced at a maximum of 75 feet. In the I-93 Northbound Atlantic Avenue Tunnel area, the drainage flows to low points of the tunnels and associated ramps. From the low points the drainage is directed to a low point pump station located in Ventilation Building No. 3. After primary treatment by oil/water separation the effluent is discharged to an adjacent combined sewer.

The D020B SDC will be responsible for overall final design of the tunnel drainage systems including all pumps, valves, exposed intermediate piping, motor starters, oil/water separators and other appurtenances. The D020B SDC will also provide verification of the preliminary engineering and directive information including piping dimensions, piping requirements and inlet spacing and sizes affecting final design of the I-93 Northbound Atlantic Avenue Tunnel area structures.

The elements of the tunnel drainage system which are to be designed as part of the I-93 Northbound Atlantic Avenue Tunnel and associated ramps structure include embedded gravity drain pipes and inlets, embedded and buried discharge piping and all miscellaneous embedded drains such as the walkway gutter drains, exhaust air duct drains and miscellaneous niche drains which will discharge directly on the roadway.

10.4 Fire Protection

As described in the "Fire Protection Concept Report," numerous subsystem elements will be integrated to provide an efficient and effective fire protection and detection system throughout the Central Artery/Third Harbor Tunnel project. As a part of this overall fire protection system, a system of dry standpipe zones shall be provided within the tunnels.

Within the tunnel and associated ramps, the system shall consist of a single main header mounted above each ceiling. A riser will extend from the main header down to a niche, providing a two-way gated hose valve connection mounted against the wall. Each zone shall be capable of being pressurized from either end via at-grade siamese hydrants. The specific location of these hydrants shall be coordinated with and approved by the City of Boston Fire Department.

Verification of pipe sizes, valve arrangements and system schematic will be performed by the D020B SDC who is responsible for the final design of the fire protection system. The I-93 Northbound Atlantic Avenue Tunnel SDC is responsible for the preparation of contract plans for the fire protection system.

10.5 Temporary Mechanical Systems

Temporary systems will be necessary during construction of the I-93 Northbound Atlantic Avenue Tunnel and associated ramps. These systems include de-watering, heat and ventilation for the health and safety of workers, and a water supply and standpipe system for fire protection. The permanent mechanical systems for tunnel drainage, ventilation and fire protection are not to be considered available for use by the construction contractor(s) during construction.

The above requirements shall be reflected by the I-93 Northbound Atlantic Avenue Tunnel Section Design Consultant in the contract documents for the construction of the I-93 Northbound Atlantic Avenue Tunnel and associated ramps and shall include all codes, regulations and/or guidelines pertinent to the provisions of such temporary systems.

13.0 Operations and Maintenance

13.1 General

The operations and maintenance concepts are presented here to provide the Section Design Consultant with an overall understanding of the completed project. Detailed requirements will be described in the Operations and Maintenance Manual. Factors for the SDC to incorporate into their project design should include:

- o System Component labelling.
- o Product consistency, i.e., minimize the number of vendors for each equipment type.
- o Transferral of all vendor catalogs and data sheets to project operator.
- o Evaluation of spare parts and specialized tool requirements.
- o Product reliability statistics.

13.2 Operating Concepts

The following subsections provide a brief description of the operating parameters and the control philosophies.

13.2.1 Traffic

The TSCS portion of the IPCS monitors motorist activity and provides for minimum delays and optimum throughput by providing the operations staff with accurate and current information. Operators will evaluate the information, choose from the menu options and implement the various traffic strategies necessary to alleviate congestion.

The D022A SDC will develop response procedures to include the following actions by the operations staff pertaining to traffic surveillance and control.

- o response to a detection alarm
- o verification by CCTV monitors, roadway display graphics or on-site personnel
- o dispatching emergency response crews
- o implementing pre-selected traffic control strategies
- o broadcasting of radio messages to motorists
- o supervising operations via CCTV
- o advising outside agencies affected by changes in conditions

A number of strategies will be developed to handle the changing roadway conditions.

Traffic control strategies will include:

- o Normal Traffic Flow
- o Lane and Roadway Closure
- o Congested Traffic Flow

- o Incidents
- o Fire
- o Roadway surface changes
- o Visibility changes

13.2.2 System Monitoring

The IPCS will report on the status of all project equipment. In addition to the traffic related equipment, the OCC will be provided with both warning and trouble alarms on various mechanical and electrical equipment. A few of the conditions to be monitored are as follows:

- o traffic volume and occupancy detectors
- o mechanical and electrical equipment status
- o carbon monoxide and hydrocarbon levels within confined areas
- o security alarms
- o overheight and overweight vehicle detection

When the equipment produces an alarm, the operator will choose from a menu of options which will rectify or address the immediate condition and will notify maintenance supervision. There will be close coordination between both the operations and the maintenance staff until the equipment is back in operation.

13.2.3 System Control

Given the magnitude of this project and the number of systems and equipment, there is a need for remote as well as local control.

Control strategies will be developed for the following:

- o bypass configuration during repair and replacement
- o emergency operations
- o abnormal condition response
- o fire detection and suppression system monitoring.

The strategies will require both internal and external agency coordination

13.2.4 Fire Protection/Detection

There are several devices which will signal a fire. Operators will verify the severity and type of fire using in-tunnel CCTV and will view their monitors for alarm condition locations. The OCC will also initiate a call to the Boston City Fire Department dispatcher via direct telephone line to verify the alarm and location plus set up a communications link with responding units.

Ventilation fans for the zone in which the fire is located will be switched to the exhaust mode and the supply side will be reduced. Ventilation strategies are complex and will be modeled for the facility.

13.2.5 Policing

The State Police will be governed by the present agreement between the Department of Public Safety and the Massachusetts Turnpike Authority.

The project will also be employing ramp metering during peak periods which will require enforcement. All communications between the State Police and the facility will be directed through the Operations Control Center. The State Police frequency will be monitored by the Control Center for reports concerning the operations and maintenance of the Central Artery/Tunnel Facilities.

13.2.6 Emergency Access/Egress

In the event of an emergency, the Operations Control Center may need to evacuate a portion of the facility. Emergency stairs are being designed both for the egress of motorists and the access of emergency and fire personnel.

Cross passages between tunnel sections will also be monitored by the OCC. All doors will be numbered for quick identification on a graphic alarm system.

13.2.7 Security

The OCC will also oversee the security of the entire facility. Operators will be notified of an intrusion into any of the project buildings and will contact the appropriate enforcement agency for response.

13.3 Maintenance Concepts

Maintenance activities can be divided into one of five categories:

1. Inspecting
2. Testing
3. Cleaning
4. Preventive Maintenance
5. Repair and Replacement

13.3.1 Inspections

Inspection schedules will be generated based on manufacturers recommendations and shall be conducted to identify early warning signs of failure.

13.3.2 Testing

Testing of all equipment shall be scheduled to check performance and control logic. Testing shall be accomplished periodically to assure equipment meets specifications.

Uninterrupted power supplies and battery systems will be checked periodically. Fan cycling and speed control will also be checked periodically. Corrosion control systems will require frequent scheduled testing.

13.3.3 Cleaning

An aggressive cleaning program is required. Maintenance personnel will be performing basic janitorial duties within each of the facilities buildings including cleaning floors, washing windows, refuse removal and servicing rest rooms. There will be a need to pressure wash the buildings regularly, and clean up including sweeping of roadways. The clean up of the grounds and park lands are also required. Cleaning will also be required on the drainage systems and throughout the project's major structures.

With an average annual snowfall of 42 inches in the Boston area, snow removal activities will be carefully planned and implemented by the operations and maintenance group. Ramps and boat sections will be cleaned to provide minimum disruption to traffic flow.

13.3.4 Preventive Maintenance

All project equipment will be incorporated into a component and system labelling program. Under this format, a computerized maintenance management system will be instituted in which a scheduled preventive maintenance program will be implemented.

13.3.5 Repair and Replacement

There will be a need for both repair and replacement of equipment. It will be necessary to maintain spare parts and provide storage, a computerized system for inventory control, and warranty administration.

Equipment will be transported to the central maintenance site for replacement or will be brought to an electrical/ mechanical workshop to be repaired.

Each of these four maintenance categories will need to be provided on the project. These elements can be grouped under the following headings.

- o Major structures
- o Roadways and grounds
- o Vehicles and heavy road equipment
- o Mechanical and electrical equipment

13.3.6 Major Structures

Major structures on the CA/T Project include:

- o Third Harbor Tunnel
- o Seaport Access Tunnel
- o Central Artery Underground Freeway
- o CANA Ramps
- o South Boston Interchange
- o Service and Administration Building
- o Toll Plaza Facility
- o Ventilation Buildings
- o Emergency Stations
- o Roadway Maintenance Buildings
- o Pump Stations
- o Electrical Substations
- o I-93/I-90 Interchange
- o East Boston Interchange

13.3.7 Roadway and Grounds

There will be a need to maintain residual land adjacent to the roadway. This will include the maintenance of all trees, shrubs, flowers and grass.

13.3.8 Vehicles and Heavy Road Equipment

The maintenance group will be responsible for the upkeep of all the facility vehicles and equipment. They will install the necessary equipment into all State Police Vehicles and provide any necessary repairs.

13.3.9 Mechanical and Electrical Equipment

A preliminary list of M&E equipments to be maintained is as follows:

- o 13.8 KV Substations
- o 13.8 KV 480 V Unit Subs
- o Motor Control Centers
- o 13.8 KV Breakers
- o Diesel Generators
- o Battery Rooms
- o Ventilation Fans
- o Drainage Pumps
- o Numerous roadway and tunnel lights.

14.0 RIGHT-OF-WAY IMPACTS

14.1 Major Property Owners

There will be approximately fourteen (14) properties affected by Contract D011A. The major property owners are: The Massachusetts Bay Transportation Authority, Dewey Square Tower Associates, and the Federal Reserve Bank of Boston. The last two mentioned properties are registered land.

14.2 Impact Upon Properties

There will be no fee takings required as part of this Contract. The major impact will be the requirement of permanent sub-surface easements together with temporary construction easements. Impacts are shown in detail on the preliminary right-of-way plans submitted with this report.

14.3 Affected Buildings

There should be no impact to the buildings abutting this Contract.

15.0 Traffic Engineering

15.1 GENERAL

As shown in Figure 1, the Proposed Action, Design Contract D011A Project Alignment extends from south of Kneeland Street at the I-93 Northbound mainline tunnel portal to the north at Congress Street. North of Kneeland Street the Design Contract D011A limits are primarily bounded on the east and west by the existing Atlantic Avenue corridor. The following major highway components are included within the Design Contract D011A limits:

- o A new I-93 Northbound mainline roadway tunnel under Atlantic Avenue (beginning south of Kneeland Street) to Congress Street.
- o A surface arterial street system will be created that will extend from south of Kneeland Street to Congress Street and be integrated with the City's local street system. The surface arterial street system is composed of existing city streets and new surface streets which provide the necessary continuity from south of Kneeland Street to Congress Street.
- o New on ramps to the Proposed I-93 Northbound mainline tunnel roadway system.

This chapter addresses future travel demand and general traffic composition and then proceeds to a detailed discussion of operations of the I-93 mainline, ramp, and surface streets within the Design Contract D011A limits.

The traffic operations of the CA/T Project area components located immediately to the north of the Design Contract D011A limits are addressed within the Design Contract D017A (Congress Street to North Street) and south of Design Contract D011A, within D009A (South Bay Interchange) contract documents.



FIGURE

1 PROPOSED ACTION - DESIGN CONTRACT DO11A PROJECT ALIGNMENT

THE COMMONWEALTH OF MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS
CENTRAL ARTERY (I-93)/TUNNEL (I-90) PROJECT
SUPPLEMENTAL EIS/R

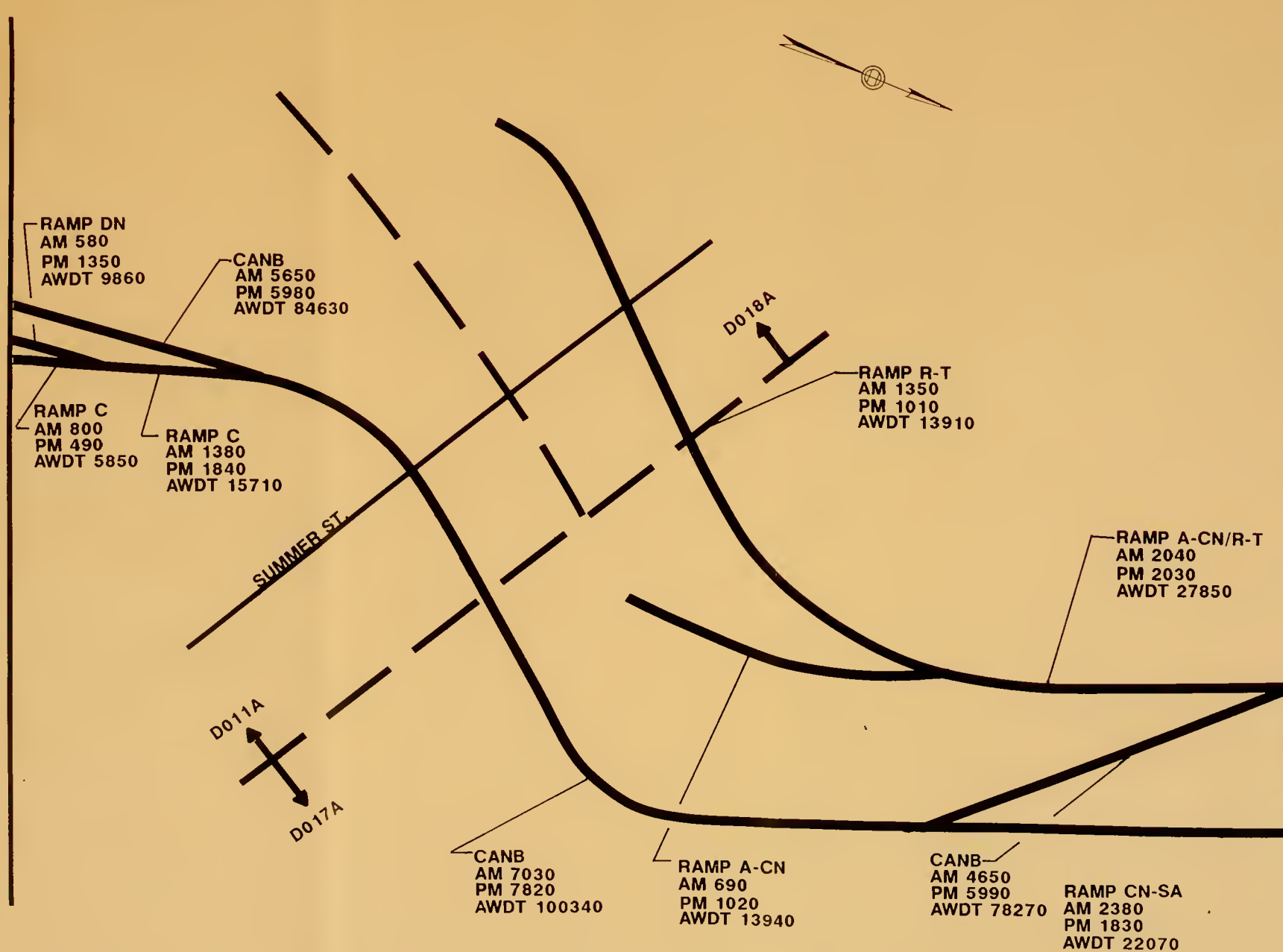


Year 2010 - Design Year Traffic Volume Estimation

Year 2010 and 1998 traffic volume forecasts were generated using the CA/T Project TRANPLAN travel forecasting computer model. The Year 2010 is the CA/T Project design year and 1998 is the scheduled construction completion date for all project components within the Central Area. The TRANPLAN travel forecasting model predicts total travel demand throughout the CA/T Project study area based on land use activity forecasts and an estimate of vehicle trips generated per unit of land use activity and accessibility. The trips generated are then assigned to the study area roadway network based upon the criterion that a vehicle will travel from its origin to its destination along the route requiring the least travel time. A more detailed description of the travel forecasting methodology is documented in the Central Artery/Third Harbor Tunnel Project Detailed Travel Model Documentation Report.

From the CA/T Project TRANPLAN travel forecasting computer model, AM and PM peak hour traffic volumes within the project study area boundaries were generated for analysis purposes. The Average Weekday Traffic (AWDT) volumes within the CA/T Project study area boundaries were generated for comparison purposes. The AM and PM peak hour traffic analyses of the CA/T Project roadway components located within the Design Contract D011A limits are discussed later in this report.

Figure 2, Design Contract D011A Major Facilities Traffic Volume Forecasts, Year 2010, shows the projected AM and PM peak hour traffic and AWDT volumes forecasted for the I-93 Northbound mainline roadway located within the Design Contract D011A limits. Figure 2 also displays forecasted traffic volumes for the I-93 Northbound mainline roadway ramps which interconnect with the surface arterial street system.



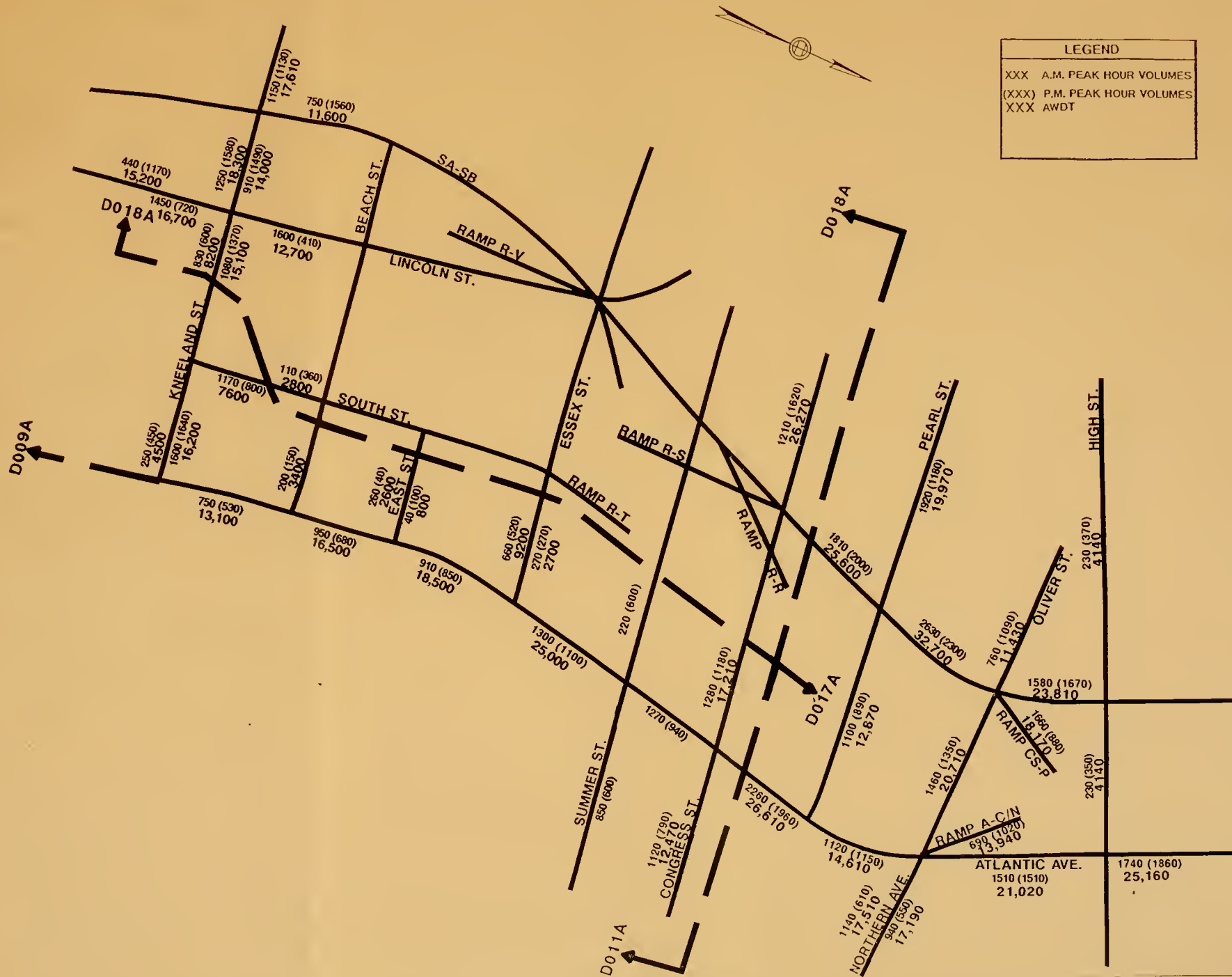
DESIGN CONTRACT D011A
MAJOR FACILITIES TRAFFIC VOLUME FORECASTS
YEAR 2010

Figure 3, Design Contract D011A, Selected Roadway Forecasted Peak Hour and AWDT Volumes, Year 2010 shows the AM and PM peak hour traffic volumes and AWDT traffic volumes within Atlantic Avenue corridor of the CA/T Project Design Contract D011A. The Atlantic Avenue corridor Design Year 2010 TRANPLAN generated AM and PM peak hour turning movement traffic volumes within the Design Contract D011A limits are shown on Figure 4, Design Contract D011A, Peak Hour Intersection Turning Movement Volumes, Year 2010. The local street peak hour traffic operations forecasted for the Year 2010 are discussed within the I-93/Central Artery Central Area Traffic Report.

The year 1998 peak hour traffic volumes forecasted for the Atlantic Avenue corridor within the Design Contract D011A limits are shown on Figure 5, Design Contract D011A, Selected Roadway Forecasted Peak Hour Volumes, Year 1998 and Figure 6, Design Contract D011A, Peak Hour Intersection Turning Movement Volumes, Year 1998.

Level Of Service Description

Level Of Service (LOS) is defined as a qualitative measure describing operating conditions that include such factors as speed, travel time, maneuverability and safety. As noted in the 1985 "Highway Capacity Manual" (HCM) Special Report 209 by the Transportation Research Board there are six defined Levels Of Service with letter designations from "A" to "F". LOS "A" represents the best traffic operating characteristics with free flow conditions. LOS "F" describes the worst conditions or failing traffic operations with high levels of delay and or congestion experienced by motorists. These conditions are briefly described below for basic freeway segments, ramp merges, and signalized intersections.



DESIGN CONTRACT D011A
SELECTED ROADWAY FORECASTED PEAK HOUR AND AWDT VOLUMES
YEAR 2010



DESIGN CONTRACT D011A
PEAK HOUR INTERSECTION TURNING MOVEMENT VOLUMES
YEAR 2010

FIGURE

4



FIGURE 5
 DESIGN CONTRACT D011A
 SELECTED ROADWAY FORECASTED PEAK HOUR VOLUMES
 YEAR 1998



DESIGN CONTRACT D011A
PEAK HOUR INTERSECTION TURNING MOVEMENT VOLUMES
YEAR 1998

FIGURE

6

LOS Criteria For Basic Freeway Segments

For basic freeway segments, the density of the traffic stream based on the traffic volume demand and the available roadway capacity (number and width of available travel lanes) are the parameters used to define LOS. The densities used to define LOS are as follows:

Criteria for Basic Freeway Sections

<u>LOS</u>	<u>Characteristics</u>	* Density (passenger cars/ mile/lane)
A	Free flow, highest speed, highest maneuverability	≤12
B	Stable flow, high speed, high maneuverability	≤20
C	Stable flow, medium speeds, less maneuverability	≤30
D	Stable flow, medium speeds, high density	≤42
E	Unstable flow, low speeds, higher density	≤67
F	Breakdown in flow, stop-and-go speeds, highest density	>67

* Upper-limit

LOS Criteria For Ramp Merges

The operational characteristics of ramp merges are dependent on the merge flow rate in passenger cars per hour (pcph) at the intersection point of the merging ramp and mainline roadway to which the ramp is merging. The merge flow rate is comprised of the ramp traffic and mainline roadway "lane 1" traffic volume. Lane 1 is the mainline roadway travel lane adjacent to the ramp merge and consequently the travel lane most impacted by the ramp merge effects. The HCM merge flow rate criteria used to define LOS include:

LOS Criteria for Ramp Merges

<u>Level of Service</u>	<u>Merge Flow Rate (passenger cars/hour)</u>
LOS A	< 650
LOS B	< 1050
LOS C	< 1500
LOS D	< 1800
LOS E	< 2000
LOS F	Widely Variable

LOS Criteria For Signalized Intersections

The LOS analysis for signalized intersections was performed using the Massachusetts Environmental Protection Agency (MEPA) approved "CINCH" software program. CINCH utilizes the operational analysis methodology of the 1985 HCM. The operational analysis of signalized intersections is an evaluation of the capacity of an intersection considering the details of traffic signal timing and phasing in addition to roadway geometry and related pedestrian activity given the traffic demand. It provides an assessment of whether or not the intersection capacity is likely to be exceeded for a given set of demand volumes and intersection geometry for the intersection as a whole and by intersection approach. The LOS results for signalized intersections analyzed using the CINCH program are expressed in terms of stopped delay per vehicle as described on the following page.

<u>Level of Service Criteria for HCM Operational Analysis</u>		
<u>LOS</u>	<u>Characteristics</u>	<u>Stopped Delay per Vehicle (seconds)</u>
A	Little or no delay, most vehicles do not stop at all.	5.0 or less
B	Short traffic delays, more vehicles stop than for LOS A causing higher average delay.	5.1 to 15.0
C	Average traffic delays. The number of vehicles stopping is significant, although many still pass through without stopping.	15.1 to 25.0
D	Long traffic delays. More vehicles stop on the average. Individual cycle failures become noticeable.	25.1 to 40.0
E	Very long traffic delays. LOS E is considered to be the limit of acceptable delay. Individual cycle failures are frequent.	40.1 to 60.0
F	Severe congestion. LOS F delay is considered to be unacceptable to most drivers. This condition often occurs with over-saturation, i.e., when arrival flow rates exceed the capacity of the intersection.	greater than 60.0

15.2 HIGHWAY TRAFFIC OPERATIONS - YEAR 2010

The I-93 Northbound mainline roadway within the CA/T Project area boundaries begins south of Kneeland Street in what is commonly referred to as the I-93/I-90 Interchange Area. The mainline roadways of both I-93 and I-90, and the supporting connector ramps between the mainline roadways of these highways pass through the I-93/I-90 Interchange. The I-93 Northbound mainline roadway within the Design Contract D011A limits begins as a three lane tunnel section as it passes under Kneeland Street continuing north under Atlantic Avenue. Within this section of roadway the I-93 Northbound mainline roadway has a Year 2010 forecasted traffic volume of 5650 vehicles per hour with an operating speed of 35 mph and LOS E during the AM peak hour. During the PM peak hour, the Year 2010 forecasted traffic volume is 5980 vehicles per hour with an operating speed of 33 mph and LOS E.

At Essex Street, the I-93 Northbound mainline is joined by the one lane on Ramp C/DN from the right where the I-93 Northbound mainline roadway increases to a four lane roadway. Ramp C/DN has a forecasted AM and PM peak hour traffic volume of 1380 and 1840. The operating conditions on Ramp C where it meets the I-93 Northbound mainline roadway during the AM peak hour is LOS D and LOS E during the PM peak hour.

Ramp C is from the Massachusetts Turnpike (I-90) eastbound mainline roadway which crosses through the I-93/I-90 Interchange area. Prior to merging with the I-93 Northbound mainline roadway, Ramp C is joined by Ramp DN in the vicinity of Kneeland Street. North of the Ramp C merge, the I-93 Northbound mainline roadway has a Year 2010 forecasted traffic volume of 7030 vph and an operating speed of 40 mph. During the PM peak hour, the forecasted traffic volume is 7820 vph and an operating speed of 33 mph. LOS E operating conditions will exist during both the AM and PM peak hour. The I-93 Northbound mainline roadway continues northerly under Atlantic Avenue from the Ramp C merge to Summer Street where it passes beneath the MBTA Red Line tunnel. North of Summer Street, the I-93 Northbound mainline roadway continues as a four lane roadway within the existing Central Artery corridor to Milk Street.

15.3 Surface Street Intersections

The intersections of Atlantic Avenue at Summer Street and Congress Street are considered sensitive to queueing and traffic signal coordination problems when considered in terms of traffic operations on Purchase Street. Although the Purchase Street intersections at Summer Street and Congress Street are not included within the Design Contract D011A limits, queueing and traffic coordination issues have been addressed. Where there is a high potential for adverse queueing impacts resulting from excessive delays at adjacent intersections or the close spacing of two adjacent intersections as in the case of diamond type interchanges, the "PASSER-III-88" method of analysis for the Year 2010 AM and PM peak hour was used. PASSER-III-88 is a traffic engineering software package developed by the Texas Department of Highways and Public Transportation to analyze permitted or traffic responsive, fixed sequence signalized diamond interchanges. Although some closely spaced local street intersections do not create a "true" diamond interchange, this software analysis methodology best addresses the impacts of vehicles queueing through adjacent intersections and the traffic signal synchronization that would be required between the intersections. The results of the 2010 AM and PM peak hour PASSER-III-88 analysis and intersection planning method analysis are discussed within the I-93/Central Artery Central Area Traffic Report. Roadway geometry changes required to improve traffic operations between two adjacent intersections have been performed based on the PASSER-III-88 analysis results. The HCM "Planning Method" analysis of the 2010 AM and PM peak hour traffic volumes is also discussed within the I-93/Central Artery Central Area Traffic Report.

The 1998 AM and PM peak hour LOS analysis results for the surface roadway intersections within the Atlantic Avenue corridor included within Design Contract D011A were obtained by using the signalized intersection capacity analysis methodology based on the 1985 HCM criteria discussed in section 15.1. The AM and PM peak hour traffic volumes generated for the year 1998 were used to determine the sequencing of traffic movements within each intersection upon removal of the existing Central Artery viaduct structure within Downtown Boston.

The results of the 1998 AM and PM peak hour signalized intersection analysis located within the CA/T Project Design Contract D011A limits are shown in Table 1, Proposed Action Design Contract D011A, Signalized Intersection Level of Service Analysis, Year 1998.

Table 1:
Proposed Action Design Contract D011A
Signalized Intersection Levels of Service Analysis
Year 1998

<u>Intersection</u>	<u>APPROACH</u>	<u>AM Peak Hour</u>		<u>PM Peak Hour</u>	
		<u>AVG. DELAY</u>	<u>LOS</u>	<u>AVG. DELAY</u>	<u>LO</u>
		<u>(sec)</u>		<u>(sec)</u>	
Atlantic Avenue at Kneeland Street INTERSECTION	EB	36.7	D	34.1	D
	NB	5.2	B	7.0	B
		8.1	B	12.6	B
Atlantic Avenue at Essex Street INTERSECTION	EB	14.6	B	16.7	C
	NB	19.4	C	18.1	C
		16.9	C	17.4	C
Atlantic Avenue at Summer Street INTERSECTION	EB	22.3	C	20.4	C
	WB	24.0	C	21.1	C
	NB	11.1	B	14.4	B
		14.7	B	17.6	C
Atlantic Avenue at Congress Street INTERSECTION	EB	28.6	D	21.3	C
	WB	40.3	E	27.6	D
	NB	35.0	D	26.1	D
		33.9	D	24.2	C

15.4 TRAFFIC SIGNAL WARRANTS

Traffic signal warrant studies determine the necessity for signalizing the intersections located within the CA/T Project Design Contract D011A study limits. The traffic signal warrants evaluated are based on the 1988 FHWA Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) signal warrant justification requirements. The MUTCD signal warrant justification evaluates intersection operations in terms of eleven different criteria in order to ascertain if a traffic signal is required. The installation of a traffic signal can be considered required when one or more MUTCD traffic signal warrants are met. The evaluation is based on intersection traffic volume data, existing traffic controls, pedestrian traffic flow volume data, accident data, local environmental conditions, and traffic peaking factors. The eleven traffic signal warrant evaluations discussed within the MUTCD include:

- Warrant 1 - Minimum vehicular volume
Met when traffic volumes at the intersection major and minor street meet or exceed the criteria listed within the MUTCD during the same eight hours of an "average" day.
- Warrant 2 - Interruption of continuous traffic
Met when the traffic volumes on the major street are excessive and traffic entering from the minor street is expected to experience excessive delay and or hazards. MUTCD lists major and minor street volume criteria required over an eight hour period of an "average" day.
- Warrant 3 - Minimum pedestrian volume
Met when intersection or mid-block pedestrian crossing volumes exceed criteria specified in MUTCD.
- Warrant 4 - School crossings
Satisfied when a determination is made that gaps in traffic are not sufficient to allow for the number and size of groups of school children at the school crossing.

- Warrant 5 - Progressive movement
Met upon determination that providing a traffic signal will allow for better traffic flow or traffic progression within the traffic stream.
- Warrant 6 - Accident experience
Generally met when accident frequency criteria shown in MUTCD is satisfied.
- Warrant 7 - Systems
Met when traffic flow volumes during the peak hour exceed 1000 vehicles in addition to meeting Warrants 1, 2, 8, 9 and 11 during particular time periods.
- Warrant 8 - Combination of warrants
Met when eighty percent of the criteria listed in Warrants 1 and 2 are satisfied.
- Warrant 9 - Four Hour Volumes
Satisfied when the traffic volumes listed in the MUTCD are met over a four hour period.
- Warrant 10 - Peak Hour Delay (measured in the field)
Satisfied when due to extreme delay experienced on the minor street approach to a major roadway the criteria for delay is met and traffic volumes on the minor street exceed the limitations listed within the MUTCD.
- Warrant 11 - Peak Hour Volume
Met when the traffic volumes on the minor street and major street approaches to an intersection are in excess of the volumes shown in the MUTCD over a one hour period.

Traffic signal warrant analysis of intersections being designed is generally performed using data for the Year 1998 "opening day" traffic flow conditions. Within the CA/T Project Design Contract D011A limits, the five signal warrant thresholds pertaining to vehicular traffic flow (Warrants 1, 2, 8, 9, and 11) have been fully evaluated using the CA/T Project 1998 TRANPLAN traffic modelling network. The results of the traffic signal warrant analysis performed for the intersections located within the Design Contract D011A limits are shown in Table 2, Proposed Action Design Contract D011A Vehicular Signal Warrant Analysis, Year 1998.

As shown in Table 2, four intersections located within the Design Contract D011A limits met at least one of the vehicular signal warrants evaluated.

Table 2:
Proposed Action Design Contract D011A
Vehicular Signal Warrant Analysis
Year 1998

<u>Intersection</u>	<u>Vehicular Signal Warrant</u>				
	<u>1</u>	<u>2</u>	<u>8</u>	<u>9</u>	<u>11</u>
Atlantic Avenue at Kneeland Street	met	met	met	met	met
Atlantic Avenue at Essex Street	-	-	-	met	met
Atlantic Avenue at Summer Street	met	-	met	met	met
Atlantic Avenue at Congress Street	met	-	met	met	met

Consequently, all of the intersections listed in Table 2 will be designed with traffic control signal equipment as shown on the Traffic and Transportation drawings within the D011A Scoping Package Submittal.

The local street system traffic control equipment utilized within the Design Contract D011A limits should be designed and constructed in accordance with Boston Transportation Department (BTD) criteria. The operations and maintenance of all local street system traffic control equipment will be assumed by the BTD through a Traffic Control Agreement with the MDPW upon completion of the CA/T Project within the Design Contract D011A limits.

The surface street restoration which includes all urban design elements such as street furniture, landscaping and finish materials is discussed within Chapter 7.0 Architecture.

17.0 CONSTRUCTION STAGING AND TRAFFIC MANAGEMENT

17.1 Assumptions

Construction will be accomplished using the soldier pile and tremie concrete (SPTC) wall method of excavation support. Following the installation of the SPTC walls, deck beams and timber decking will be installed over the entire alignment of this project. Excavation and concrete placements can then be performed using equipment stationed on the timber decking above the proposed tunnel. Both vehicular and pedestrian traffic will also be maintained on the timber decking. However, the traffic routing will be staged to accommodate construction.

See Fig. 17.1 for D011A design limits.

17.2 Selected Methods and Techniques

The method of support of excavation selected for the bulk of construction on this project is slurry walls using soldier piles and tremie concrete (SPTC). Some sections allow the use of sheet piling, however this is generally where the tunnel lies close to the surface. One such area is the southerly end of this contract where it meets the South Bay Interchange near Station 84+00 CANB. Sheet piling is anticipated to run from there to the north side of Kneeland Street, where the walls change to soldier piles with tremie concrete (SPTC).

The South Station Transportation Center will construct a slurry wall between it and CANB; this wall will be designed to CANB requirements for use during I-93 tunnel construction. It runs from the portal of Ramp C to the South Station Headhouse.

SPTC wall construction is anticipated to be accomplished in 10' to 20' lengths, leapfrogging along Atlantic Avenue on first the east side and then the west side of the alignment. Intermediate supports (caissons) and cross bracing will then be installed, and decking placed between the completed SPTC wall sections, so that traffic can be maintained on the surface of the decking. The tunnel excavation and construction can then proceed below the decking.

During the excavation operation, existing utilities must be supported and maintained in place under the decking. During the backfill operation, these utilities will be relocated, as required, and placed in their proposed permanent locations.

During these operations traffic must be maintained to provide for the safe and orderly flow of pedestrian, vehicular, and construction traffic. Traffic management plans are reflected in four stages as described on the Traffic Staging Plans (See Fig. 17.2 through 17.5). All work and/or traffic staging adjacent to interfacing construction contracts is to be coordinated. Cooperation between adjacent contractors is emphasized.

In the C17A section the CANB off ramp to Northern Avenue will be closed in the early stages of construction. Traffic to the northbound viaduct from Northern Avenue will be rerouted south to the Congress Street northbound on ramp. In addition, the entrance to the Congress Street on ramp will be modified during the C17A contract. C11A traffic management must include consideration of the resulting construction staging requirements which stem from the additional and/or changed traffic volumes and patterns.

Throughout construction the contractor will be required to erect all necessary signs, lighting, and traffic control devices, as necessary, to accommodate the work. In addition, the contractor will be required to provide access for emergency vehicles, delivery vehicles, buses, and pedestrians at all times during construction.

17.3 Maintenance of Traffic/Construction Staging

The contractor will be required to maintain both vehicular and pedestrian traffic along Atlantic Avenue and each of the cross streets at all times during construction. However, of the three cross streets between Kneeland Street and Summer Street, only two must be maintained at any one time during the slurry wall (SPTC) or decking operations. See drawings CA-PD-C-269 thorough CA-PD-C-272 for maintenance of traffic during construction.

17.4 Staging Areas

The Contractor will be allowed to establish a construction staging area within the Contract Limits providing the proposed area has been submitted to, and approved by the Authorized Representative. Construction staging areas outside the Contract Limits are the responsibility of the Contractor. The Contractor is required to reach agreement with the property owner or lessee of the property prior to use. A copy of this agreement should be forwarded to the Authorized Representative to provide proof of permission to use the property.

17.5 Schedule

See Stages 1 through 4 of the Construction Staging Drawings. Fig. 17.2 through Fig. 17.5.



FIGURE 17.1

CONSTRUCTION STAGING I

ACTIVITY	YEAR					
	1991	1992	1993	1994	1995	1996
1. RELOCATE UTILITIES (CONTRACTS C14B1, C14B2, C14C1, C14C2, C15A1, C17A1) (ITEMS 3, 4, 5, 7, 8, 9)						
2. CONSTRUCT PARKING STRUCTURE ON PARCEL 7 (CONTRACT C16A1)						
3. REMOVE NB ON-RAMP FROM NORTHERN AVE (CONTRACT C16C1)						
4. BEG MAINLINE CON (ON E SIDE - BET KNEELAND ST & NORTH ST (CONTRACTS C1A1, C15A1, C15A2, C17A1, C17A2)						
5. UNDERPIN RED LINE STATION (CONTRACT C1A1)						
6. REMOVE PORTION OF FEDERAL RESERVE PARKING STRUCTURE (CONTRACT C1A1)						
7. CON BOAT SEC @ NORTH OF RAMP ON-SA & TEMP OFF-RAMP BOAT SECTION (CONTRACT C17A2)						
8. REMOVE NB OFF-RAMP TO NORTHERN AVE (CONTRACT C17A1)						
9. CON TEMP ON & OFF-RAMPS TO & FROM CENTRAL ARTERY (CONTRACTS C15A1, C15A2)						

LEGEND

PROPOSED BRIDGE/VIADUCT STRUCTURE

PROPOSED SURFACE ROADWAY

PROPOSED TRANSITION ROADWAY

PROPOSED ROADWAY TUNNEL

PROPOSED ROADWAY BY OTHERS

PROPOSED TRAFFIC MOVEMENT ON BRIDGE/VIADUCT STRUCTURES, SURFACE ROADWAYS AND TRANSITION ROADWAYS WITH NUMBER OF LANES

PROPOSED TRAFFIC MOVEMENTS IN TUNNELS WITH NUMBER OF LANES

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FEET

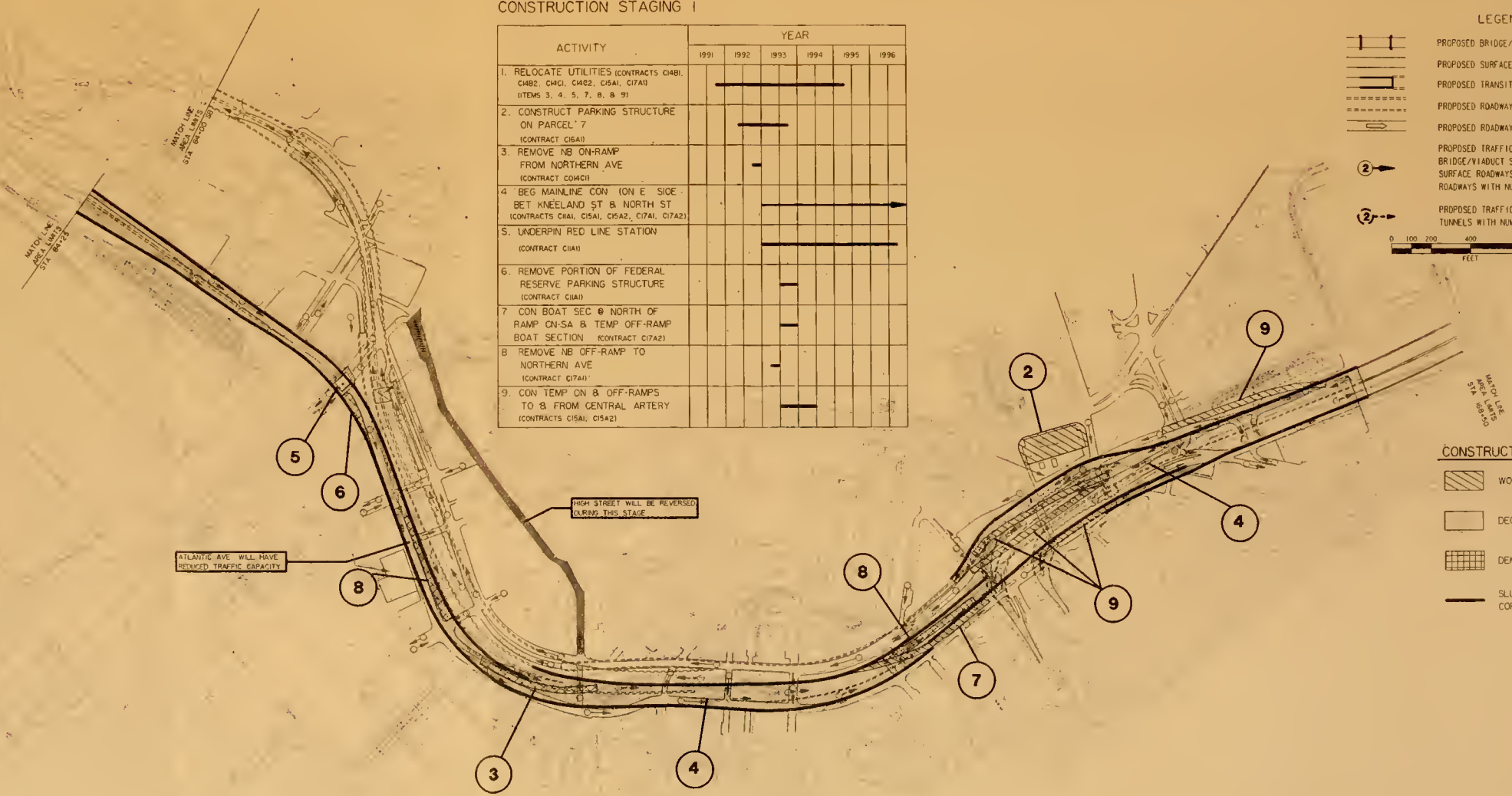
CONSTRUCTION LEGEND

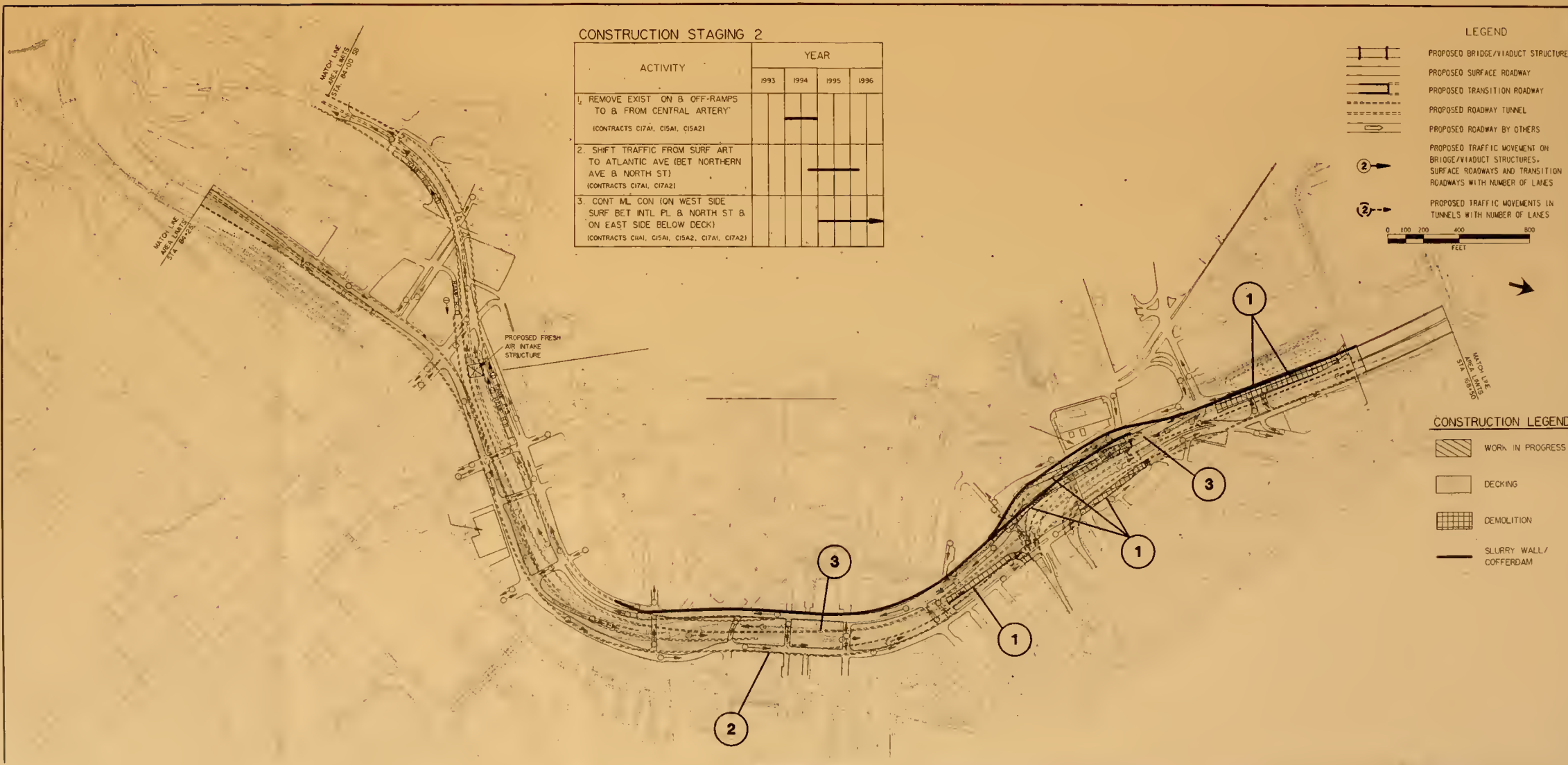
WORK IN PROGRESS

DECKING

DEMOLITION

SLURRY WALL/ COFFERDAM





CONSTRUCTION STAGING 2

ACTIVITY	YEAR			
	1993	1994	1995	1996
1. REMOVE EXIST. ON B OFF-RAMPS TO B FROM CENTRAL ARTERY (CONTRACTS C17A1, C15A1, C15A2)				
2. SHIFT TRAFFIC FROM SURF ART TO ATLANTIC AVE (BET NORTHERN AVE & NORTH ST) (CONTRACTS C17A1, C17A2)				
3. CONT. ML. CON. (ON WEST SIDE SURF BET INTL PL. & NORTH ST & ON EAST SIDE BELOW DECK) (CONTRACTS C14A1, C15A1, C15A2, C17A1, C17A2)				

LEGEND

- PROPOSED BRIDGE/VIADUCT STRUCTURE
- PROPOSED SURFACE ROADWAY
- PROPOSED TRANSITION ROADWAY
- PROPOSED ROADWAY TUNNEL
- PROPOSED ROADWAY BY OTHERS
- PROPOSED TRAFFIC MOVEMENT ON BRIDGE/VIADUCT STRUCTURES, SURFACE ROADWAYS AND TRANSITION ROADWAYS WITH NUMBER OF LANES
- PROPOSED TRAFFIC MOVEMENTS IN TUNNELS WITH NUMBER OF LANES

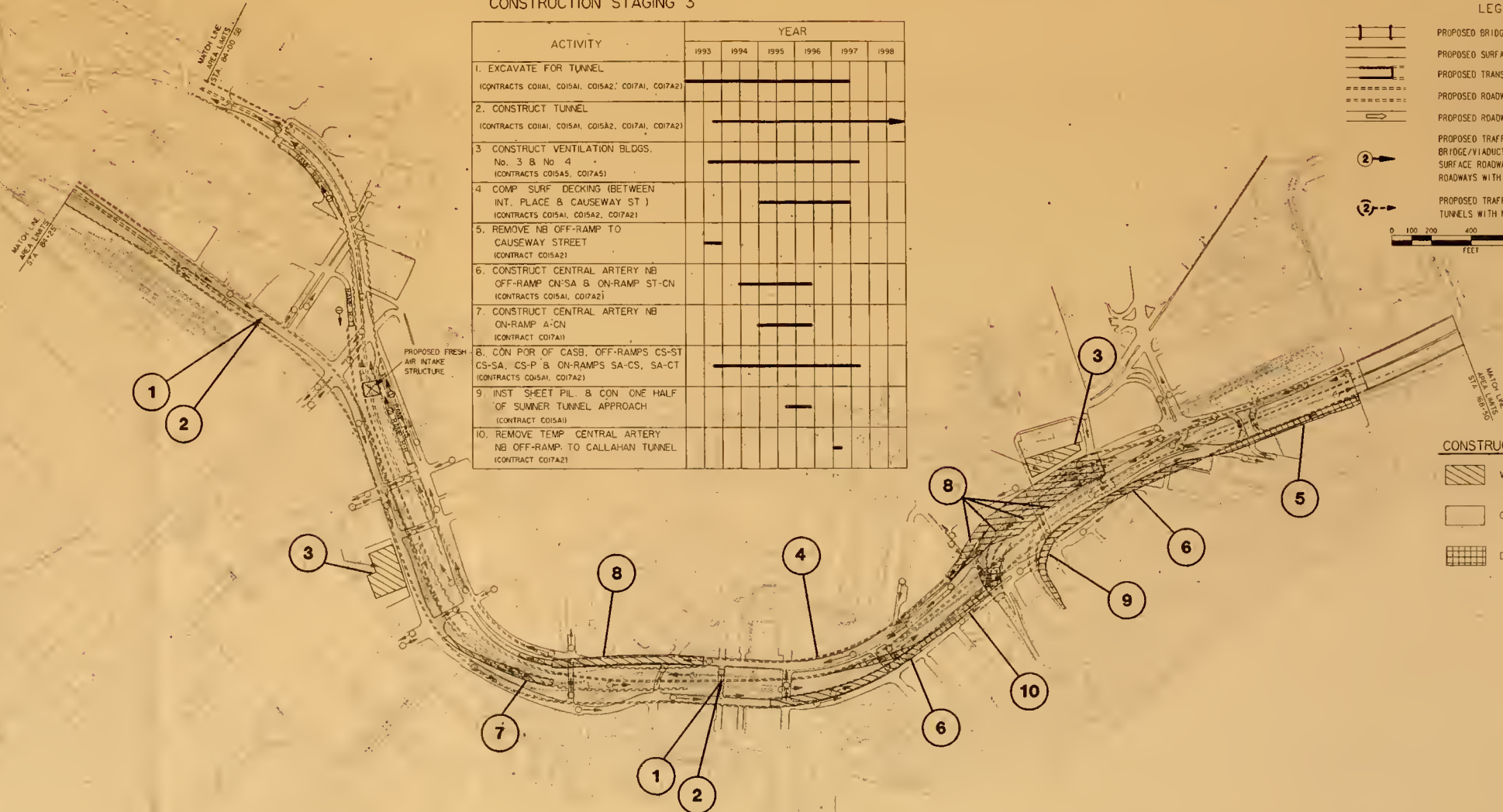
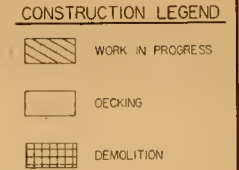
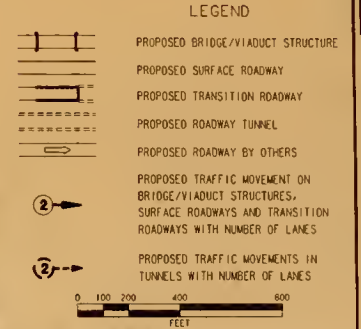
0 100 200 400 800
FEET

CONSTRUCTION LEGEND

- WORK IN PROGRESS
- DECKING
- DEMOLITION
- SLURRY WALL / COFFERDAM

CONSTRUCTION STAGING 3

ACTIVITY	YEAR					
	1993	1994	1995	1996	1997	1998
1. EXCAVATE FOR TUNNEL (CONTRACTS CO1A1, CO1A1, CO1A2, CO1A1, CO1A2)						
2. CONSTRUCT TUNNEL (CONTRACTS CO1A1, CO1A1, CO1A2, CO1A1, CO1A2)						
3. CONSTRUCT VENTILATION BLDGS. No. 3 & No. 4 (CONTRACTS CO1A5, CO1A5)						
4. COMP SURF DECKING (BETWEEN INT. PLACE & CAUSEWAY ST.) (CONTRACTS CO1A1, CO1A2, CO1A2)						
5. REMOVE NB OFF-RAMP TO CAUSEWAY STREET (CONTRACT CO1A2)						
6. CONSTRUCT CENTRAL ARTERY NB OFF-RAMP ON-SA & ON-RAMP ST-CN (CONTRACTS CO1A1, CO1A2)						
7. CONSTRUCT CENTRAL ARTERY NB ON-RAMP A-CN (CONTRACT CO1A1)						
8. CON POR OF CASB, OFF-RAMPS CS-ST CS-SA, CS-P & ON-RAMPS SA-CS, SA-CT (CONTRACTS CO1A1, CO1A2)						
9. INST SHEET PIL. & CON ONE HALF OF SUMNER TUNNEL APPROACH (CONTRACT CO1A1)						
10. REMOVE TEMP CENTRAL ARTERY NB OFF-RAMP TO CALLAHAN TUNNEL (CONTRACT CO1A2)						



CONSTRUCTION STAGING 4

ACTIVITY	YEAR	
	1996	1997
1. PLACE TRAFFIC IN DEPRESSED CENTRAL ARTERY NORTHBOUND	*	
2. MOVE CENTRAL ARTERY SB TRAFFIC TO NB SIDE OF EXISTING ROADWAY SOUTH OF NORTH ST.	—	—
3. CONSTRUCT PORTION OF CENTRAL ARTERY SB RAMP CS-P BETWEEN INTERNATIONAL PLACE & CONGRESS ST. (CONTRACT C17A6)	—	—
4. REMOVE PORTIONS OF EXISTING CENTRAL ARTERY & TEMPORARY RAMP (CONTRACT C15A2)	—	—
5. CONSTRUCT REMAINING PORTIONS OF CENTRAL ARTERY SB RAMP CS-CT, SA-CS & SA-CT (CONTRACT C15A1)	—	—
6. INSTALL SHEET PILING & CONSTRUCT ONE-HALF OF CALLAHAN TUNNEL APPROACH (CONTRACT C15A1)	—	—
7. MAKE IMPROVEMENTS TO WESTERN HALF OF DEWEY SO. TUNNEL (CONTRACT C18A1)	—	—

LEGEND

- PROPOSED BRIDGE/VIADUCT STRUCTURE
- PROPOSED SURFACE ROADWAY
- PROPOSED TRANSITION ROADWAY
- PROPOSED ROADWAY TUNNEL
- PROPOSED ROADWAY BY OTHERS
- PROPOSED TRAFFIC MOVEMENT ON BRIDGE/VIADUCT STRUCTURES, SURFACE ROADWAYS AND TRANSITION ROADWAYS WITH NUMBER OF LANES
- PROPOSED TRAFFIC MOVEMENTS IN TUNNELS WITH NUMBER OF LANES



CONSTRUCTION LEGEND

- WORK IN PROGRESS
- DEMOLITION

APPENDIX A

(To the Preliminary Design Report)

CONSTRUCTION IMPACT MITIGATION

1.0 GENERAL

The Massachusetts Department of Public Works requires that the work of the CA/T Project be performed with as little disruption to the public as absolutely necessary.

This document is intended to provide general mitigation requirements to be considered by the Section Design Consultant during the final design effort. Site-specific mitigation requirements are described in the Preliminary Design Report.

The objective of construction impact mitigation is to minimize disruption to:

- Traffic
- Public Transportation
- Vehicular Access
- Pedestrian Access
- Parking

and, to minimize the disruption resulting from:

- vibration to adjacent buildings
- noise/air and other environmental concerns

In order to accomplish this objective, the following elements, where applicable, shall be addressed in the construction documents:

- Suggested construction sequencing that would reduce construction impacts.
- Limitation on time of construction operations.
- Available contractor laydown and use areas.
- Contractor access routes.
- Adjacent building access and operational requirements.

- Traffic maintenance requirements.
- Pedestrian access and walkway requirements.
- Localized noise/vibration sensitivities (see CA/T Conservator's Report as referenced in Article 2.7 of this document and the May 1990 Draft SEIS).

2.0 GUIDELINES

2.1 Traffic Maintenance:

The goal during construction is to maintain traffic and transportation service with minimum disruptions to the mobility of the commuting system. The construction document prepared by the SDC shall require the contractor to:

- A. Implement the Traffic Management Plan developed by the SDC.
- B. Identify and submit detour plans or plans of temporary decking systems to maintain necessary traffic patterns.
- C. Clearly sign detours, temporary lane constrictions and closing of roads.

2.2 Transportation Alternatives:

The SDC shall be aware of all transportation alternatives which interface with the design. Many transportation alternatives are under development such as increased MBTA subway, railroad, and bus services.

2.3 Pedestrian Access and Flow:

Safe pedestrian access and flow along streets will be interrupted by construction sites. Safe continuous pedestrian flow along alternate routes must be provided. The SDC shall:

- A. Identify pedestrian walkways and pedestrian entrances to buildings that must be maintained during construction.

- B. Design and specify protective walkways and barriers as appropriate to each site and stage. (CA/T design standards and guidelines for walkways and barriers will be provided to the SDC.)

2.4 Vehicular Access:

Vehicular access to loading and delivery areas, pick up and drop off points, and parking facilities will be impacted and may be temporarily interrupted by construction operations. The SDC shall:

- A. Identify all locations where vehicular access may be impacted by the work.
- B. Obtain data pertinent to the nature of the vehicular access areas such as peak use hours, volume of vehicles, and impact of temporary disruption.
- C. Indicate in the construction documents that the contractor shall identify, design, or specify temporary facilities that minimize disruptions.
- D. Identify alternate locations for loading zones, delivery and passenger drop-offs, where appropriate.

2.5 Signage & Lighting:

Used as a public information tool, signs will convey information on detours, relocated pedestrian ways and altered access to business. The SDC shall:

- A. Identify and note in the construction documents clear, visible locations for signs to motorists, pedestrians, rail commuters and building occupants.
- B. Design adequate lighting of temporary pathways, roadways and signs for public information and safety.
- C. Indicate and specify lighting requirements in the construction documents.

2.6 Parking:

Parking losses will be an unavoidable consequence of construction operations. The SDC shall:

- A. Define construction boundaries to minimize disruption to parking.
- B. Consider, and where appropriate, specify, methods resulting in the least possible construction impact to existing parking areas.

2.7 Historic Resources:

The SDC shall become familiar with the CA/T Historic Resource Concept Report, December 1988 and any subsequent reports produced by the Conservator for this project and design in accordance with the guidelines and requirements stated.

2.8 Building & Structure Support:

Some buildings or structures in the vicinity of construction are susceptible to effects from the construction operation. These impacts include effects attributable to ground settlement and vibrations. The SDC shall:

- A. Refer to the Conservator's Report for the identification of sensitive historic buildings and structures in proximity to the proposed construction area.
- B. Conduct structural analyses of any building or structure, as identified in the Preliminary Design Report, likely to be impacted by the construction operation.
- C. Specify appropriate building protection methods for the affected structures.

2.9 Construction Method:

Implementation of various construction methods and techniques will have a direct bearing on the impact experienced by surrounding neighborhoods. The SDC shall:

- A. Be cognizant of alternative methods for performing the work.

- B. Identify locations where particular sensitivities exist and, where conditions warrant, specify suggested methods that reduce impacts.

2.10 Integrated Pest Management:

The SDC shall become familiar with the CA/T Integration Pest Management Program.

2.11 Environmental:

The SDC shall become familiar with the CA/T Environmental Impact Statement and design in accordance with the commitments stated.

2.12 Construction Arts:

A construction arts program will be an integral part of construction activities on this project. A CA/T Arts Administrator will coordinate all arts related activities for the project. Where the locations for construction arts are identified by the Management Consultant, the construction art areas shall be shown in the contract drawings, or indicated in the specifications, (e.g., provision of primed wall barriers to open ground with viewing spots).

COMMONWEALTH OF MASSACHUSETTS

CENTRAL ARTERY (I-93)/TUNNEL (I-90) PROJECT

UNDERPINNING THE RED LINE
AT SOUTH STATION

STUDY REPORT

NOVEMBER 1990

PREPARED FOR THE DEPARTMENT OF PUBLIC WORKS
BY BECHTEL/PARSONS BRINCKERHOFF

BURTON P. KASSAP, P.E.
CONSTRUCTION MANAGER

JEFF BRUNETTI, P.E.
AREA DESIGN MANAGER

K.K. SEE-THO, P.E.
DESIGN MANAGER

UNDERPINNING THE RED LINE AT SOUTH STATION
ON THE PROPOSED CENTRAL ARTERY PROJECT, BOSTON

SUMMARY

The present proposed alignment of the Central Artery (northbound) passes under the Massachusetts Bay Transit Authority (MBTA) South Station Red Line at the intersection of Atlantic Avenue and Summer Street. To accomplish this task, this report will present a method of construction for underpinning the South Station Red Line that utilizes jackpipe tunneling techniques, in conjunction with alternate pit underpinning and square set mining methods. It is the primary concern of this undertaking to properly safeguard the running rails of the MBTA during all phases of construction, to avoid any penetration into the subway that might prevent continuous train operations, avoid interface with the riding public and to provide a construction free environment at the intersecting street surfaces. Emphasis is placed on minimizing the exposure of the unsupported areas of excavation during the underpinning operation and minimizing the amount of deflection of the structural members used to support the South Station Red Line during and after load transfer.

Each method of the proposed underpinning relies upon and uses positive structural elements, provides for remedial action, in the event unforeseen soil movements occur, controls the amount of structural deflection, satisfies the concerns mentioned above and minimizes the risks during and after construction.

STUDY REPORT
UNDERPINNING THE RED LINE AT SOUTH STATION

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1.0 INTRODUCTION

1.1 Background and Location

The Central Artery/Third Harbor Tunnel Project consists of approximately 7 miles of new and reconstructed roadways, which includes the construction of a widened underground portion of Interstate 93 (northbound), that extends from Kneeland Street in a northerly direction to Causeway Street. This route, which is along Atlantic Avenue, is in the heart of downtown Boston. The overall project is being designed to improve both the capacity and safety of the existing highway facilities, and will provide an additional harbor crossing for access to Logan Airport. The current accident rate on the Central Artery is nearly twice the nationwide average for the Interstate System. The major elements of the proposed reconstruction will substantially reduce that rate by an estimated 35%. The Artery/Tunnel Project will have beneficial transportation impacts in every part of central Boston and the surrounding area.

Traffic volumes are forecast to average 221,100 vehicles

per day along the Central Artery between Kneeland and Causeway Streets which will require a widening from six to eight lanes with additional operational lanes for weaving movements, acceleration and deceleration.

The portion of the proposed (northbound) Central Artery (I-93) that this study report addresses consists of a four lane reinforced concrete structure whose subgrade distance below street level is approximately 90 feet where it will pass under the existing MBTA Red Line subway station at South Station.

The location of the subway station is directly beneath the busy intersection of Summer Street and Atlantic Avenue (See Drawing S-285). Emanating from the South Bay Interchange, Atlantic Avenue presently serves as one of the termination roadways for the end of the Massachusetts Turnpike (I-90). Summer Street provides a main roadway crossing from the financial district in Boston to the industrial section of South Boston including the seaport access.

The intersection is the location of a complex of important buildings, including the 32 story Federal

Reserve Bank of Boston Building and garage located on the northeast corner, the 5 story South Station railroad building and depot servicing Amtrak and the Commuter Rail System on the southeast corner, and the 46 story One Financial Center Building on the southwest corner. The Dewey Square Tunnel vent shaft structure and bus terminal occupy the northwest corner. The intersection handles heavy vehicular and pedestrian traffic. Maintaining this traffic in an uninterrupted manner, as well as commercial services to this area, are primary objectives.

1.2 Purpose and Goals

The construction of the (northbound) Central Artery under the existing MBTA South Station Red Line will require a method of underpinning that will safeguard the station structure and running rails from any settlement or excessive deformation. Also, it is imperative that both passenger service and train operations not be interrupted. Towards those goals, a series of studies were undertaken that resulted in developing a method which employs jackpipe tunneling techniques in conjunction with alternate pit underpinning and soft

ground mining methods.

The purpose of this report is to describe this method in detail so that it is clear to all concerned what is intended for the critical underpinning of the Red Line subway station.

2.0 UNDERPINNING DESIGN FACTORS AND PROCEDURE

2.1 General

The technical term "Underpinning" is used to denote the placing of new foundations or supports under existing structures. The design of a successful underpinning scheme is dependent upon the following factors:

- An assessment of the condition of the structure to be underpinned, to determine its ability to sustain the loads and stresses that may be imposed by the underpinning operation.

- An examination of the geologic profile that falls within the influence lines of the structure that

is to be underpinned.

- An assessment of the environmental aspects of the structure as it pertains to its continual and functional usage during construction.
- The development of a method which safeguards all concerned. This applies to both the people involved in the use of the facility during and after underpinning, as well as, those involved in the underpinning construction operation itself.

2.2 Existing Structure Evaluation

The existing South Station Red Line was constructed in 1914/15 under the auspices of the Boston Transit Commission. Cut and cover construction was the method used to build this two level (i.e. platform/track and mezzanine) structure. The depth of the structure subgrade is about 55 feet below the street surface and is founded on hard grey silt and clay (See Drawing S-290).

During the original construction, interlocking steel

sheetpiling was utilized for the lateral earth support. Based on a review of the original structural contract drawings and recent site field inspections, it appears that this subway station is in remarkably good condition. All beams and columns are rolled structural I-beams, many of which are reinforced with riveted plate members. Concrete slabs between the beams are reinforced with various size steel square bars that are spirally deformed. The concrete appears quite sound considering its age, signs of leakage, cracks and deterioration are visible, but are minimal and have been repaired and replaced by recent modernization contracts.

It is important to note that this examination of the existing structure is critical to the decisions of underpinning and the particular methods to be used. The appraisal revealed a structure that is working well within its original design criteria and is capable of taking certain measured stresses and strains that might be imposed by the underpinning operation.

2.3 Geotechnical Review

The geologic profile (See Drawing S-290) shows

approximately 20 feet of fill measured from the street surface. This is underlain for the next 35 feet by grey silts and clays (blow counts of 20 to 40 blows/ft.). Below the station subgrade, the soil begins to develop higher blow counts and reveals varying layers of silty till and fine to coarse sands which predominate the till material. These occur in thickness ranging from 35 to 55 feet below the station subgrade to the top of rock. One must be cognizant of the occasional layers or pockets of relatively clean sand and gravel that are known to exist in the Boston area. These have the tendency of yielding significant short term flows of water and soil into the excavations. The top of bedrock as shown by the borings is between 90 and 110 feet below the street surface. The bedrock underlying South Station is primarily a fine grained argillaceous rock of low metamorphic grade known as argillite. The argillite commonly appears in varying degrees of alteration. The upper surface is generally weathered and partially decomposed. The extent of this layer is quite varied, but ultimately overlies sound or unaltered rock. The sound rock is usually hard, and typically dark grey.

The determination of the water table level in the

till is an important factor in evaluating the underpinning alternatives. Previous investigations (Mueser Report - Appendix I) showed that the ground water level is not consistent over the entire site and slopes downward to the north. Tests have indicated a highly variable water level in the till ranging from 17 to 30 feet below ground surface within a horizontal distance of 50 feet. It was reported that there are some minor leaks into the subway station that drain to a sump and pump facility. This could be the cause for a localized water level depression in the till. It is anticipated that further borings will be made adjacent to this structure in the immediate future to better define the hydraulic gradient and the characteristics of the subsurface soil material.

2.4 Environmental Assessment

It is estimated that the South Station Red Line is used by more than 17,000 commuters daily. Recent construction modifications have provided for underground passageways from the South Station Red Line to the adjoining Commuter Railroad Terminal, also known as South Station. Pedestrian access and flow both beneath

and on the street surface is critical and must be maintained. Any disruption of this service by construction operations during the operating hours cannot be tolerated. Any penetration into the running tunnels and station must be avoided. The maintenance of continual and functional usage of the MBTA facilities is a prime consideration and determining factor for the use of this method of underpinning.

3.0 UNDERPINNING ANALYSIS

3.1 Overview

In viewing the profile of the existing structure, it becomes apparent that there are separate distinct zones or areas to be considered (See Drawings S-286 and S-287). In a vertical perspective, we are looking at a two level structure. The lower level contains the running rails that carry the trains and the train platforms. The upper mezzanine level services the toll collection and passenger distribution facilities. The zone between Columns B and D is considered critical with respect to underpinning methods. It is desirable to have as rigid a support as possible that will achieve

minimal movements due either to deflection of the supporting members or any disturbance of the supporting soils which could cause settlement during underpinning. The underpinning members should be capable of spanning approximately 85 feet in the east-west direction and 55 feet in the north-south direction. Viewing the structure laterally (See Drawing S-286), we see the mezzanine overhangs, underground passageways, stairways and escalators. These areas were viewed as being less critical than those previously discussed. The station structure should be capable of tolerating some strain and added stress without effecting train operations or public safety. It is recognized that the working mechanical escalators may require some special support treatment to keep potential movement within operating tolerances during underpinning.

When examining the South Station Red Line and the proposed alignment of the Central Artery (northbound) in Plan View, (See Drawing S-285) it is apparent that in order to keep the surface street intersection clear of construction activity, (which could impede both vehicular and pedestrian movements), the length of underpinning must be extended along the I-93 alignment

from column Line A to the southern most wall of the underground passage that connects One Financial Center with the railroad station. Cut and cover construction utilizing temporary roadway decking, would be carried up to Line A coming from the north and the outside wall of the underground passage, coming from the south. Temporary bulkheads would be constructed across Atlantic Avenue using reinforced concrete slurry walls at the limits of the extended underpinning. Access to the underpinning operation can be accommodated from below the decking and through the temporary bulkheads. The temporary slurry wall bulkheads will act as soil containment structures to prevent the soil and ground water from moving laterally from under the station when the underpinning operation and excavation commences.

3.2 Proposed Method of Underpinning

The method of underpinning chosen to provide support of the South Station Red Line and subway station in part, will utilize jacked steel pipes reinforced with post-tensioning strand, filled with concrete and stressed to predetermined values. These jacked pipes, which are installed tangent to each other, will act as

beams to provide continuous support directly below the station trackbed and platforms. They will be installed from jacking pits constructed under the decking and in the cut outside of the temporary bulkhead wall on the north side (See Drawing S-286). These pipes will all be jacked from the north side using an alternate/opposite sequence starting from the centerline of the proposed Artery. They will exit through the temporary concrete slurry wall on the south side, facilitating reuse of the cutting edge.

During this jacking operation, two parallel tunnels or adits will be mined approximately 85 feet apart (See Drawing No. S-285) on the east and west boundary of the proposed alignment. These tunnels will be constructed by the square set method and will provide access for the construction of two transverse girders and four interior girder piers (which will support the transverse girders). Also, access will be provided by these tunnels for the construction of the concrete side walls, which will be constructed using the horizontal pit board method. The walls will be constructed in an alternate sequence (See Isometric Drawing S-288), from the access tunnels.

When all of the pipes have been jacked to their final position, two transverse girder tunnels will be mined under the jackpipes, using the pipes as the roof support for these transverse girder tunnels.

Since the jackpipes are tangent to each other, the lower portions of the steel pipes may be removed to the springline leaving a series of "barrel arch" pipe segments to support the roof of the transverse girder tunnels. This removal will also afford easy access into the jackpipes for cleaning, setting end bulkheads, installing strand, concrete placement and post-tensioning. The maximum span length of the five foot diameter jackpipes acting as beams will be 55 feet. They will act as simply supported beams resting on the transverse girder beams. It is this array of jackpipe beams that will directly beneath support the station.

The transverse tunnels will subsequently be reinforced and filled with concrete to become the transverse girder beams. The girders will be supported by reinforced concrete underpinning piers that were previously excavated from the parallel access tunnels using the horizontal pit board method, down to the top of rock.

Any weathered or decomposed rock will be removed within the confines of these piers until competent sound rock is reached to develop the load bearing capacities required. The maximum span length of the transverse girders carrying the jackpipe beams is 85 feet.

Since the underpinning system will be designed to carry all of the station and overburden loads, it is unnecessary to design the structure of the northbound Central Artery to carry those loads. The underpinning structure will be designed as a permanent structure and load transfer to the Artery structure will not be required.

The Central Artery Design Department has reviewed the proposed method of underpinning so that the nominal sizing of the main structural members are verified. Deflection of those members were further analyzed to confirm that the deflections were within acceptable limits established by the criteria. More detailed information will appear in the Preliminary Design Submittal for D011A.

4.0 DISCUSSION OF METHODS

Prior to discussing the underpinning design, some comments will be made regarding the methods chosen and the reasons for their choice.

4.1 Jackpipe Tunneling Technology

Pipe jacking is a method of tunnel construction. It provides for a precast concrete pipe or steel pipe liner section to be pushed into the soil face by means of hydraulic jacks located in a jacking pit or gallery. An excavating shield or reinforced steel cutting edge will make contact with the soil at the face, behind which the succeeding pipe segments are added and jacked from the jacking pit. Excavation at the face may be by hand or by mechanical means. Pipe jacking was introduced in this country in the late 1890s on the Northern Pacific Railroad. It was used as a means of culvert construction that could be installed without disturbing or interfering with the railroad operations. Major jackpipe installations were performed in the New York and Detroit areas in the late 1950s. Jackpipe tunneling has recently become quite commonplace in England and

European Countries. It has been used principally for sewer tunnels of various diameters, in urban areas. Multiple jack pipes have also been used successfully to form a roof of a larger tunnel such as that proposed in this report.

The typical elements of a pipe jacking operation are shown in Figure A. A jacking pit or shaft must be constructed to a size that is dependent upon the diameter and length of the pipe to be jacked, the throw or extension of the jack rods and sufficient space for thrust block material that receives the total reaction from the jacking operation. The cutting edge and the first section of pipe are started into the soil from a launching pad that includes a guide rail setup or a cradle. The cutting edge and pipe passes through vertical support sheeting that must be removed. The pipe is advanced to the maximum extension of the thrusting jacks, which are hydraulically operated. The jacks are retracted, another section of pipe is lowered into place and the sequence is repeated. Bentonite may be injected between the soil and the pipe to provide lubrication at the soil/pipe interface.

The spoil or tunnel muck, as mentioned previously, may be removed by hand, a mechanical excavating arm fitted within a tunnel shield or by a sophisticated TBM. Depending upon the size and length of the jacked tunnel, the excavated spoil may be transported by wheelbarrow, muck cars, or track and locomotives. Some installations convert the spoil near the face into a slurry by the mixing and addition of water. It is then pumped and discharged to a settlement pond at the surface where space allows. De-sanders and cyclones may be employed for the removal of the solids and the slurry is recirculated back to the face. Where concrete pipe is used, extra reinforcing is required at the bell and spigot to account for possible stress concentration. The major jacking load is applied in axial compression. A pipe jacking ring is used to distribute the stress evenly and plywood cushioning material is used between pipe joints. "O"-rings or welded joints may be used for water tightness.

When steel is used, the thickness may vary depending upon the usage. It may be that the steel pipe is being used as a carrier for a permanent pipe and is, in effect, an external sleeve. The void between the sleeve

and the permanent pipe may be filled with sand or cement grout. As will be shown, the final usage of the steel pipes jacked into position in this underpinning design, serve as a form for concrete and post-tensioned support beams. Appendix III contains an example which shows the successful use of asbestos pipe jacked and used as a form for concrete filled and reinforced beams on a subway roof.

Hydraulic jacks used in jackpipe tunneling may vary in capacity from 50 tons to 500 tons each. As few as two jacks may be used, although it is common to use as many as six to jack one pipe. Placement of the jacks must be in a position around the pipe to allow for spoil removal. Operating pressures on these hydraulic systems range from 1,000 psi to 8,000 psi. Depending upon the hydraulic jack thrust available, care must be taken to assure that the maximum pipe compressive stress not be exceeded. It is not unusual to use telescopic jacks that extend to 11 feet per total "shove." A reaction block must be constructed at the pit or shaft wall to react against the jacking loads. The type of soil available for passive reaction and the space available will dictate the nature of the materials used for the

reaction. Reaction blocks made from steel sheeting, soldier piles, concrete, steel plates or cribbing are generally used.

As mentioned previously, a fabricated steel cutting edge is required on the front of the pipe string. The primary function of the edge is to protect the pipe from damage and deformation. If the soils are poor, an upper steel hood may be added to extend support to the crown, this gives the miner some protection while mucking at the face. For large diameter pipes, mechanical excavators, steering jacks, conveyors, pressurized chambers, etc., are all state-of-the-art components of modern pipe jacking procedures (See Figure A).

4.2 Dynamics of Jacking Pipe

The dynamics of jackpipe tunneling in soft ground involves only a few basic fundamentals. Overcoming ground friction and the inertia of the pipe are the two major factors. Injection of bentonite around the exterior of the pipe may be used to reduce friction during jacking. It is injected through holes fabricated or cast into pipe with appropriate fittings to prevent

backflow. The same holes may be used for cement grout injection to fill any voids and displace the bentonite after the pipe is in its final position and requires no further horizontal movement.

The lengths of jacked pipe used in this underpinning scheme are relatively short (i.e., 160 feet). However, when lengths begin to exceed 250 feet and the total thrust required becomes excessive for jacking and exceeds the compressive strength of the pipe, then intermediate jacking stations may be required. If used, it will require an external steel sleeve fitted between two pipe sections and contain a complete ring of smaller internal jacks. The jacking force produced by this internal ring reacts against the friction developed by the pipe train behind it. The distance left after retracting the jacks is then closed by using the main jacks located in the jacking pit, shaft or gallery. This action has sometimes been likened to the motion of a caterpillar. Upon completion, the intermediate jacks are removed leaving the steel shell in place. A concrete filler section is then formed and concreted in place. Utilizing this method, (i.e. several intermediate jacking stations) pipes have been jack

tunneled in excess of 1,500 feet for major sewer lines. Theoretically, there is no limit to the length that pipe can be jacked. The above is presented for informational purposes only. The scheme presented in this report will not require intermediate jacking stations.

Soils will produce varying frictional resistance ranging from 100 to 500 pounds per square foot. Clays are good soil for jacking, providing it is not of the squeezing or expanding type. The higher the percentage of silt and sand that occurs in the clay, the greater the frictional resistance. Some soils will have good stand-up time both at the vertical face as well as at the crown or arch. This phenomenon is discussed further in Section 5.0, "Soil Behavior." This allows for "some" pre-excavation at the face to develop a measured and controlled overcutting. Combined with bentonite lubrication, the high frictional resistance in the soils can be reduced without causing ground settlement and/or collapse at the face.

5.0 SOIL BEHAVIOR

5.1 Characteristics

Excavated soils within an underground confined space will exhibit specific characteristics, which allow for redistribution of stresses developed by the creation of a void. This implies that soil has the ability to structurally support itself prior to introducing any temporary or permanent tunnel supports. The soil develops an arch or dome which supports and transfers the overburden onto the ground located on both sides of the tunnel or void. This phenomenon of stress redistribution and the formation of ground arches is time related. It is a function of the type of soil, the cohesive properties, the water content, the loads that the arch is carrying and the span length produced by the arch. Until such time when structural support members may be introduced to reinforce the opening, the arch is in a state of unstable equilibrium.

The redistribution of stresses and the factor of stand-up time are one of the primary soil

characteristics that allow most of the tunneling and underpinning operations in soft ground to reach the large degree of success that has been achieved. Successful underpinning is dependent upon the understanding of this ground behavior. It is also dependent upon quality workmanship, careful planning and thorough subsurface investigations. Since underpinning performance is so closely related to limiting ground movement, some clarifying comments on categorizing ground movement will be made.

5.2 Types of Ground Movement

Ground movement, (other than that ground which is classified as firm and does not create any perceptible movement), may be categorized as raveling, running, flowing, squeezing or swelling.

Raveling Soil

A raveling soil will gradually break up into chunks, flakes or angular fragments. As time elapses, more fragments dislodge leaving a cavity which increases in

size. It is the most common form of ground behavior in an excavated condition.

Running Soil

If the soil has no or little cohesive properties, it will run and flow.

Squeezing Soil

If the soil has some cohesion but does not have a friable texture or jointing, and if the stresses are high, the soil will produce a response of squeezing into the created void, instead of breaking into fragments. Squeezing ground will slowly advance into the void without any signs of fracturing.

Swelling Soil

In stiff jointed clays, excavation opens the joints in the clay surrounding the excavated opening and causes relaxation of the stresses in the soil. Water may gradually permeate the joints and create a tendency for the soil to swell.

These typical soil behaviors have been described in order to emphasize the conditions that may be encountered with the soils present in the project area. The soil profiles shown in Drawing S-290 and the profile shown on Drawing S-286, show that the jackpipe support beams will pass through a strata of hard grey inorganic silt and clay. There are, however, some layers of sand, gravel and silts of varying consistency and strengths below the zone of proposed jackpipe support that will behave in accordance with the movements described.

6.0 CONSTRUCTIBILITY

As a result of the inherent uncertainties involved in underground construction, and considering the criticality of the subway trains and platform which are to be supported, it was decided that steel jackpipes, transformed into reinforced concrete post-tensioned structural members, is the best solution for the support system to be used directly under the trains and platforms in the critical underpinning area.

Throughout this report on underpinning the South Station Red Line, one major and recurring underpinning principle

should serve as the guiding factor in the determination of the final methodology. That principle, in the field of underground construction, is to Minimize the Unsupported Area of Exposure.

6.1 Stages of Construction

The following list of construction activities is presented to describe the sequential operations that are required to perform the underpinning described in this report and should be used in conjunction with the attached Drawings S-291, S-292 and S-293:

1. Install monitoring devices in the subway station and at street surfaces and adjoining buildings. Install slurry walls north and south of Summer Street.
2. Install deck beams, decking, utility support/relocation, and maintain traffic by staging and during "off-hours" work.
3. Excavate through deck openings to Strut Level No. 4, north and south of the station adjacent to the temporary concrete slurry wall bulkheads and

install all struts and wales as excavation progresses.

4. Construct sheeted jack pit gallery in the open cut, north of the temporary concrete slurry wall bulkhead, which has been previously decked.
5. Mine tunnels (square sets) for access to the side wall construction, girder pier pits and the transverse girder tunnels.
- 6a. Penetrate concrete slurry wall bulkheads from the north side and begin pipe jacking sequence, exiting at the south concrete bulkhead.
- 6b. Construct girder beam piers to sound rock and construct the alternate pit walls concurrently with the pipe jacking operation described in 6a.
7. Mine and construct the cross girder tunnels using the previously jacked pipes to act as the roof of the girder tunnel. Remove the lower section of the pipe to the springline. This will provide a "barrel arch" roof. Clean jacked pipes, complete

exterior grouting, set end plates, wire strand, place concrete, cure and post-tension the jackpipe beams.

8. Complete construction of girder piers, interior cross girders and pit walls. Form exterior carrier girders, place steel strand, concrete, cure and post-tension.
9. Form and place concrete for sidewall extensions and cure. Excavate soil beneath jacked pipe beams to the top of rock and break through the balance of the concrete slurry wall bulkhead and remove.
10. Begin rock removal to subgrade using non-explosive methods. Install required rockbolts, as required.
11. Construct Central Artery northbound.
12. Backfill/restore utilities, remove decking and deckbeams, and repave adjoining streets.

6.2 Assessment of Jackpipe Method

It is believed that the method of installation of steel

jackpipes best complies with the principle of minimizing the unsupported area of exposure. The following statements enumerate the support of that principle and explain how construction risk is reduced:

1. A five foot diameter steel pipe was chosen as the size to be jacked. The area at the face of this pipe is approximately 19 square feet. Should poor soils be encountered at this face, breasting boards or bulkheading can be installed quickly to restrain soil movement.
2. Excavation with hand tools affords the miner direct visual and physical contact at the face with the specific soils encountered. Probes ahead through the face are also possible.
3. Depending upon the stand-up time of the soil, the miner can visually inspect the soil immediately ahead of the cutting edge to ascertain if any voids in the crown of the jackpipe tunnel or the subgrade of the subway slab are present and are in need of filling as the work progresses.
4. If obstructions are encountered, the miner has the

ability to remove them at the face within the confined area of this size pipe.

5. The diameter of the pipe is large enough to be efficient for mining and mucking operations.
6. The steel pipe provides adequate protection for the miners. A steel hood may be used at the face for further protection if soils will not stand at the crown.
7. Pipes are jacked into the soil for initial penetration. Jacking pressures can be set to predesigned values so that overstressing the pipe will not occur or cause damage to the cutting edge, if an obstruction is encountered.
8. This method limits and isolates movement at the face to the 19 square feet of exposed area.
9. Injection of bentonite may be introduced to reduce skin friction around the pipe.
10. The pipe is a rigid, stable and positive structural member.

11. Grout or soil stabilizers may be injected into the space between the top of the jackpipe and the subgrade of the Red Line tunnels and station (from within the pipe).
12. If soil movement occurs, breasting boards may be quickly installed at the face. Poor soil may be treated through the breast boards at the face until stabilization is achieved.
13. The ability to limit ultimate deflection is achieved through post-tensioning the main structural members in stages.

6.3 Construction of Roof Support By Jackpipe Method

The jackpipes mentioned above are jacked through temporary concrete slurry wall bulkheads located across Atlantic Avenue just north of the subway station wall and just south of the underground passenger pedestrian tunnels (See Drawings S-286 and S-291, Stage I). The primary function of these walls is to retain in place those soils which are adjacent to and under the subway station complex. The jacking pits (See Drawing S-286)

will be located adjacent to the north bulkhead. Jacking will begin at the middle or centerline of the northbound Central Artery and progress alternately on both sides of the centerline. The pipe are to be jacked so that they are close as possible to each other. Final cement grouting should not be installed until the tangent pipes are in place on both sides of the pipe to be grouted.

The pipe ends will terminate at the south temporary slurry wall bulkhead. The temporary concrete bulkhead will be broken through after the cutting edge reaches that boundary. The cutting edge will be retrieved, removed and reused. After the transverse girder tunnels have been constructed and the underside sections of the pipe removed, the pipe should be cleaned. The ends of the pipes will be bulkheaded and fitted with steel plates for stressing and outfitted with post-tensioning strand. Provisions for pumping concrete shall be made through the bulkhead and the use of a slick line installed to ensure complete filling of the pipe. The strand in the pipes may be stressed from the cut (open) sides of the excavation and from the internal transverse girder tunnels at intermediate locations. In this manner, each pipe will be composed of three simply supported post-tensioned sections.

This procedure of jacking one pipe at a time under the station complex never exposes more than 19 square feet of unbraced soil in a confined and controlled environment and minimizes the potential for ground movement.

6.4 Construction of the Access Tunnels and the Transverse Girder Tunnels By Square Set Mining

In the proposed underpinning system, the transverse girder tunnels (interior and exterior) will contain the ends of the bulkheaded and concrete filled post-tensioned jackpipes. The girder tunnels themselves will be reinforced and filled with concrete. They will act as carrier girders to support the jackpipes. The side tunnels will facilitate the construction of the transverse girder tunnels and will also provide access for the girder support underpinning piers (at the ends of the transverse girders) and the lateral support sidewalls.

Some comments will be made about the transverse girder tunnels and side access tunnels shown on Drawings S-285, S-286 and S-287. The side access tunnels are

constructed by square set and timber lagging methods and become an integral part of the underpinning system. Not all underpinning is necessarily performed with "state-of-the-art" methods. "Recent" tunneling history begins around the year 1800 as the Industrial Revolution and the growth of the cities created new demands for transportation, water supply and drainage. The primary means of ground support was timbering. Excavation was carried out by pick and shovel. Muck was hauled by manpower or animals. Structural linings were made of hand laid stone masonry. Magnificent tunnels were constructed using these simple tools, many of them large size and constructed through difficult ground that would impose severe challenges even for today's technology.

In "square sets" and "wood lagging", (See Drawing S-289) a set consists of a ground sill, two vertical posts and a cap, similar to framing an opening in a building wall. The sets are installed as the mining progresses from 2 to 5 foot intervals, on center. The spacing will depend on the "heaviness" of the ground as it relates to "stand-up" time. The timber sets are precut to size and often dapped, scabbed or notched. Each timber is placed in its proper position, plumbed, squared, wedged and

secured. Lagging boards are placed outside the sets, bearing tightly against the earth to prevent any movement. This forms a continuous sheeting envelope that may, in some cases, include the floor.

If the working face shows any signs of raveling or running, the face can be similarly lagged with "breast boards". These are placed in front of and wedged to the most advanced set and can further be supported by strong backs or kickers to the previously installed set. The boards may be removed one at a time, excavated, advanced and rebraced before the next board is removed. The tunnel face is excavated from the top down. It is carefully advanced board by board, set by set, always limiting the area of exposure. In good ground, this can proceed quite rapidly. In poor ground, it can be very slow.

In running ground, a method of forepoling is utilized. It is a slow and tedious operation, but with care it is a safe one (See Drawing S-289). Poling boards (or spiles), which have been sharpened to a cutting edge are driven into the face of the heading at the crown with pneumatic hammers, sledges or jacks. When the heading

is advanced half the length of the poling boards, a new false set is put in place, which supports and takes the strain from the poling boards. The poling boards are then driven to their full penetration as the section is enlarged. Other timbers are substituted until the complete section is excavated. The upward pitch of the poling board must be enough so that the next cap may be set (about 2 inches per foot).

If the exposed area of the tunnel is large, the excavation might advance in two segments. This is known as a "heading and bench method". A top heading is constructed (driven) and supported in a similar manner as described for square sets. The bench cut lags some distance behind the heading, depending upon the ground characteristics. The operation then requires extending the side posts, resetting the sills and transferring the loads without disturbing the roof support. Utilizing "positive" structural member supports and minimizing the potential for ground loss typifies this method of construction. This method also relies on the self-supporting soil characteristics. These characteristics are used to determine the working loads on the timber bracing. It is the timber bracing that is the prime

support of the soil, until the permanent support structures are in place.

The transverse girder tunnels are constructed in a similar manner, except that the steel jackpipes already provide the roof support members. All that is needed is just the side posts and ground sills. Lateral loads at the tops of the side posts must be taken by the jackpipes by means of welded-on cleats.

6.5 Steel Horseshoe Rib Set Alternative

The adaptability of timber bracing in the tunnel mining operation has definite advantages. It should be noted, however, that this may also be accomplished by the use of a steel horseshoe rib set with steel liner plate lagging (See Figure B). This sketch was provided by Commercial Pantex Sika, Inc. and shows a perceived concept on how to support this access tunnel. The access tunnels as shown on Drawing S-285 may be constructed using these steel horseshoe rib sets installed in a heading and bench excavation process with ribs placed at 4 feet on centers.

6.6 Construction of the Girder Support Piers By Box Sheeting Method (Alternate Pit Underpinning)

The girder support underpinning piers are constructed by the method known as the box sheeting method, using horizontal pit boards.

The piers are rectangular in shape and will be constructed to a suitable depth and must bear on reasonably sound rock. The piers can be sunk to almost any depth in clays and sand using horizontal timber sheeting generally no thicker than 4 inches. Excavation is by hand tools and the soil is removed using a bucket and tripod wheel. Sometimes a motorized winch is used for lifting. Depending upon the soil characteristics and stand-up time, the horizontal pit boards can be placed one at a time (See Drawing S-289) in sets, one below the other and with the earth carefully repacked behind each board. The bottom-most pit board is kept in place by a foot block and wedge. This process is repeated until top of competent rock is reached or the bearing capacity of the pier load is reached. The pier may be keyed or doweled into the rock. Reinforcing steel is placed into the pit and concrete placed or

pumped into the shaft. The construction of the pier would precede the construction of the transverse girders so that drypacking or load transfer devices are unnecessary.

The side walls of the excavation for the Northbound Central Artery will be constructed by the same method and will be excavated in a sequence of alternate pits. This allows multiple pits to be constructed concurrently. Drawings S-286 and S-287 show the extent of pitwork to be performed as part of this underpinning scheme. The wall pits may be keyed or doweled together for continuity and load transfer. The walls extend into the access tunnels which in turn receive steel reinforcing, concrete and become the extensions of the side walls.

The area of underpinning carrying the stairway entrance, over-hangs, escalator structures, underpasses, sump pits, and previously abandoned rooms will be supported and underpinned by the same method of jackpipe beams and transverse girders. The structures are less critical than the running rails and platform areas with respect to public safety.

Temporary underpinning may be required for special conditions such as stairway overhangs. The use of minipiles, bracket piling, needlebeams and underpinning pits all present reasonable options for such temporary supports, if required.

6.7 Dewatering

Water permeation into the pits always presents a problem for underpinning. If the soils have low permeability, dewatering may be achieved by small electrically operated submersible pumps.

If a water bearing strata or aquifer is penetrated, then a dewatering system installation may be required to lower the water table and relieve the pressure.

Pressure grouting injected from within the tunnels to chock-off watering flow and the usage of grout curtains acting as cut-off walls which can be installed from the street surfaces are two possible alternatives for water control.

The movement of water carrying fines or small particles

of soil is a major concern and should be avoided or prevented from occurring.

The current available soil borings do not provide sufficient information to assess this problem. Additional boring and piezometer tests will be required (See additional comments in 7.0).

7.0 REMEDIATION MEASURES

When one views the stages of construction drawings (See Drawings S-291, S-292 and S-293), it becomes apparent that there will be an extensive network of underground adits, shafts, galleries and pits. It should be emphasized that there are specific sizes and dimensions, which are shown, that limit the magnitude of these temporary underground structures. These sizes must be in conformance with sound underpinning practice. That practice is to always be cognizant of the in-situ soil behavior that temporarily acts as part of the internal supporting structure. Deflections, arching actions, soil slippages and movements, water carrying fines, water under pressure (perched or otherwise) and yielding supports all must be considered and kept to a minimum so

as to lessen the impact and effect of construction disturbance. The known or encountered soil strength characteristics must not be exceeded or overstated. If unpredictable movements are to be anticipated, then the exposed unsupported areas (i.e. face, crown or sides) must be minimized and localized. If soil movement occurs and has been temporarily restrained, the underpinning contractor must have stand-by equipment readily available and operable to provide more permanent stabilizing techniques, such as chemical or cement grouting. These may be injected into the poor soil areas, and once stabilization is effected, the underpinning operation may resume. It may be necessary to extend and improve on a dewatering system, providing such extended dewatering is not for a prolonged period. Dewatering may cause consolidation or otherwise induce soil movements, increase loads or expose wood piling to decay action if continued for long durations.

8.0 EARTH EXCAVATION

After all of the support members have been installed, reinforced and post-tensioned, excavation through openings in the temporary concrete slurry wall bulkheads

to remove the soil beneath the station may commence from either north, south or both ends concurrently. Depending upon the specific structural design, further post-tensioning may take place on the main support and carrier girders. As the excavation proceeds to remove soil from beneath these girders, load is induced and deflection takes place. By adjusting and increasing the magnitude of post-tensioning, this deflection may be controlled and reduced considerably. Earth excavation will continue to top of exposed rock.

9.0 ROCK REMOVAL

Rock removal under the South Station Red Line will be limited to non-explosive methods. Hydraulic splitting (plug and feathering), expansive chemicals (S-Mite/Bristar) and pneumatic or hydraulic "Hoe-Ram" breaking will be allowed.

Depending upon the rock quality encountered, rock bolts should be utilized, (either cement grouted or fully encapsulated resin types). The rock will be removed in lifts, and the rock bolts should be drilled into the vertical face of the exposed rock to maintain stability

and support for the piers and lateral walls (See Drawing S-287).

10.0 INSTRUMENTATION AND MONITORING

Instrumentation and monitoring of the existing structure is outside of the scope of this report, but is obviously a necessary and important factor in determining the success of the underpinning construction methods. Settlement and movement devices must be monitored daily in the station and at ground surface during construction. It is suggested that monitoring devices be installed 12 months prior to actual construction so that a baseline datum may be established for movements and vibrations in the South Station Red Line subway structure. One of the benefits of this underpinning system is that penetration into the existing Station is not required. The operation of the subway trains is not interfered with. Drawing S-286 does in fact show provisions for drilled holes in the track invert. These holes are provided in case of an emergency that might require grouting below the track invert in the event that a void is discovered and needs to be filled. This would presume that a void was detected but not

accessible from the grout holes provided in the steel jackpipe.

11.0 SUMMARY AND CONCLUSIONS

The essential criteria for developing a constructible underpinning method that would allow construction of the proposed, northbound, Central Artery under the existing South Station Red Line calls for the following:

1. Safeguard the MBTA running rails and train operations, and protect the station from damage.
2. Avoid penetration into the subway that might prevent continuous service.
3. Avoid interface with the riding public.
4. Provide a construction free environment at the intersecting street surfaces.
5. Prevent any settlements or other deleterious impacts on adjacent buildings, services and facilities.

A method of using three construction/underpinning techniques, which emphasized minimal ground exposure and remediation, was developed and is recommended. The parallel jackpipe method is a proven technology (See Appendix I). This method was used in providing roof support in the Antwerp Metro System (1977). It has also been used for crown reinforcement in the construction of the "Hamacho" subway station for the Tokyo Metro (1979).

Pipe jacking provides for main support elements directly under the MBTA Station, and will consist of positive structural members installed below the decking from the north side of the intersection. The jackpipes will be large enough for a miner to work inside of, and small enough to limit exposure at the face. This method has the ability through controlled overcutting at the face, to relieve soil pressure at the heading caused by the jacking operation.

Square set mined tunnels and horizontal board underpinning pits are also small enough to limit exposure at the face and large enough for miners to work. Movement of the soil is controlled and limited by the specific method of construction.

The utilization of temporary concrete slurry wall bulkheads on both sides of the underpinning contribute greatly towards preventing soil displacement beneath the station.

The proposed underpinning scheme involves various proven techniques that all have the following characteristics:

- Each method relies upon, and uses structural elements, which provide direct positive support.
- Each method will control the amount of deflection.
- Each method provides for local remedial action, if required.
- Each method complies with the criteria set forth at the beginning of this report.

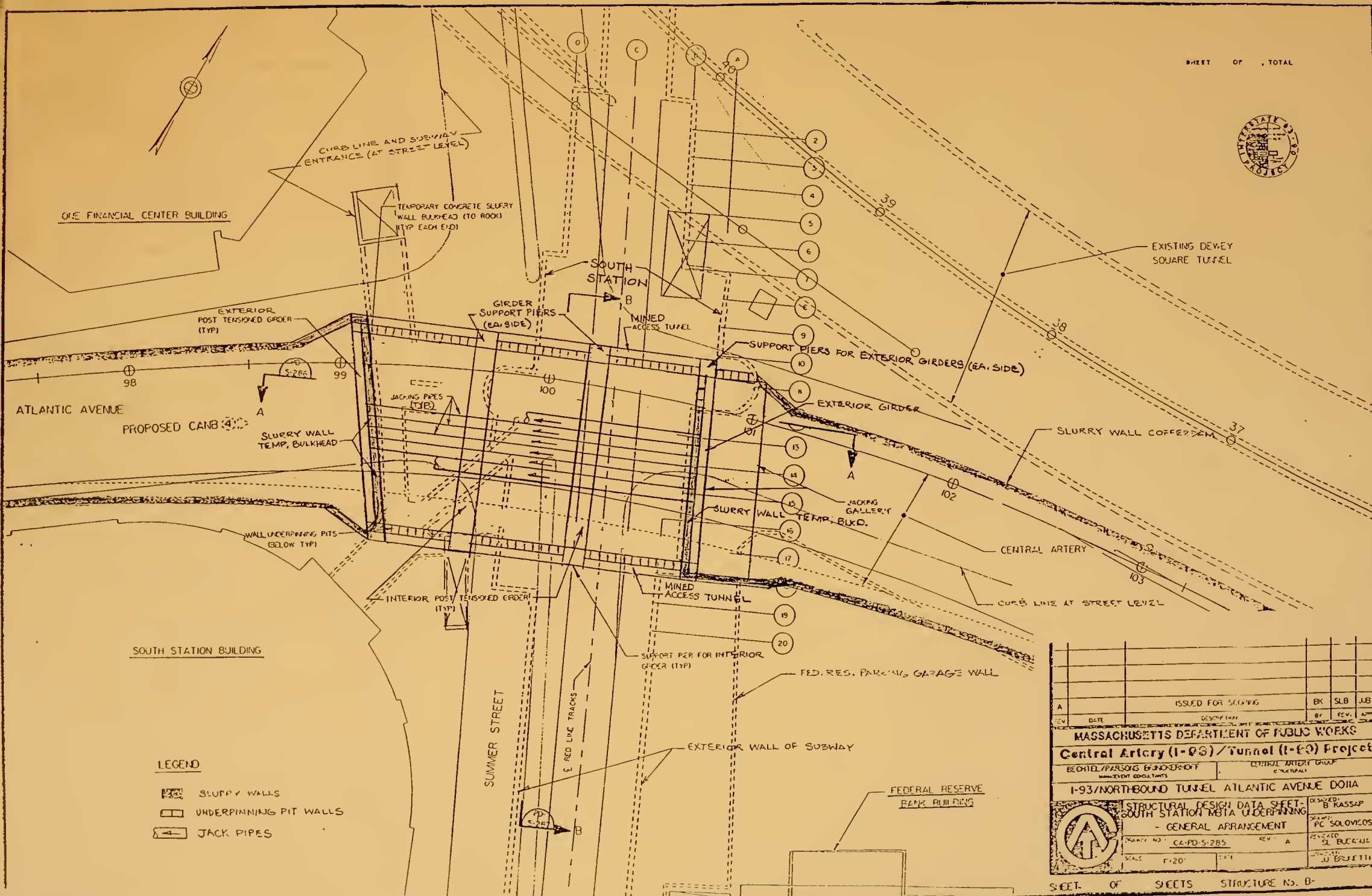
A number of alternative methods and schemes were reviewed, such as NATM, horizontal jet grouting, ground freezing, large diameter tunnel shields, (both Earth Pressure Balance and slurry face), just to name a few. While each of these methods or a combination of them offer possible solutions for underpinning the South Station Red Line, they were not chosen. The element of risk, safety and the possibility of encountering the

unexpected were weighed in each case. The ground disturbance produced by these methods was judged to be excessive for being so close to the station structure. Also, adequate remedial action could not be assured in emergency conditions involving possible localized failures. The potential damage to the Station and the public were all too apparent. These methods did not merit the criteria set forth as a basis for developing the underpinning concept.

It is a recommendation of this report to obtain, if possible, further borings in the area and below the track inverts to better examine and evaluate the hydraulic gradient at various depths and the quality of the underlying rock for pier support.

APPENDIX I - REFERENCES

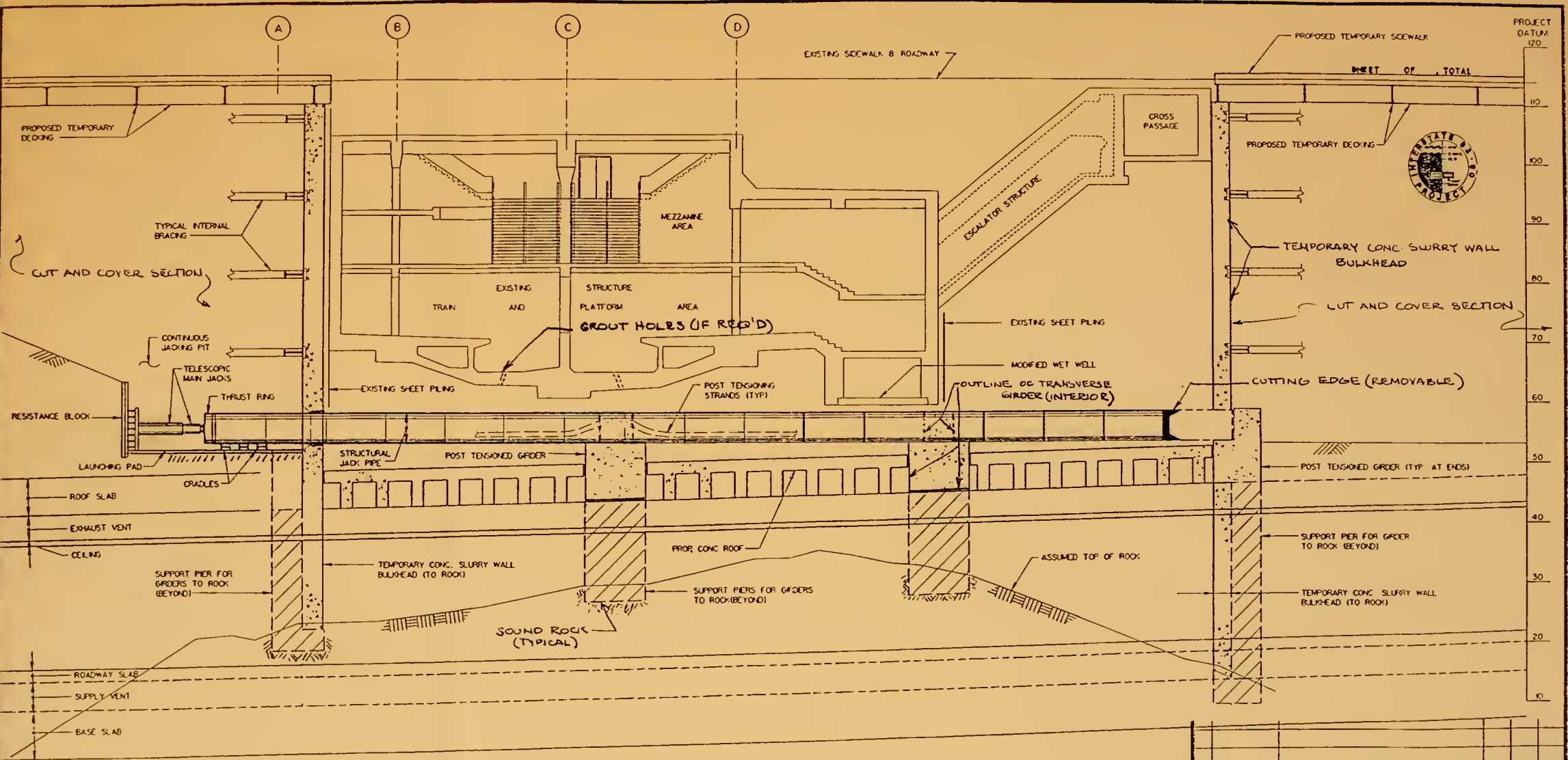
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LEGEND

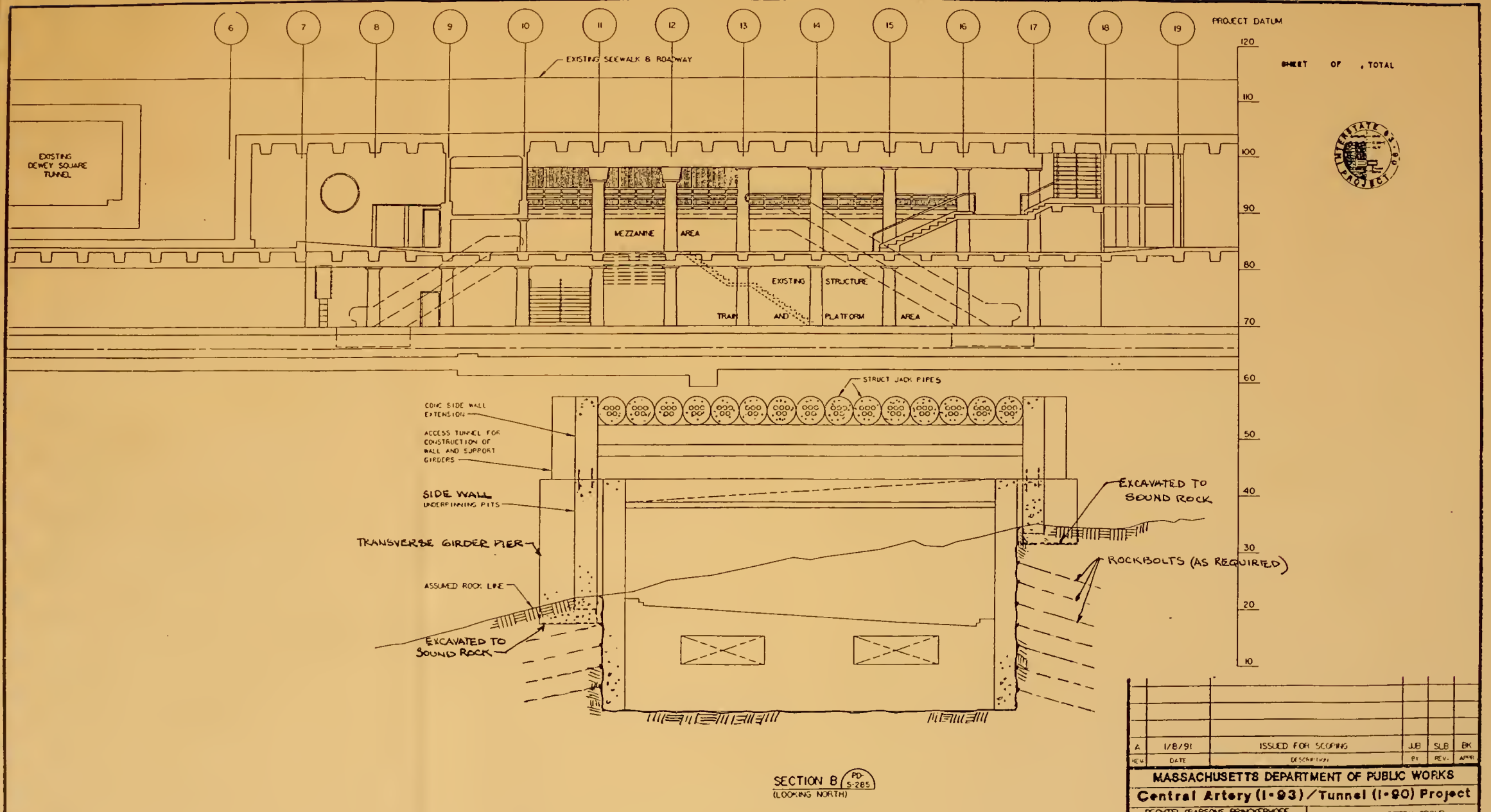
- SLURRY WALLS
- UNDERPINNING PIT WALLS
- JACK PIPES

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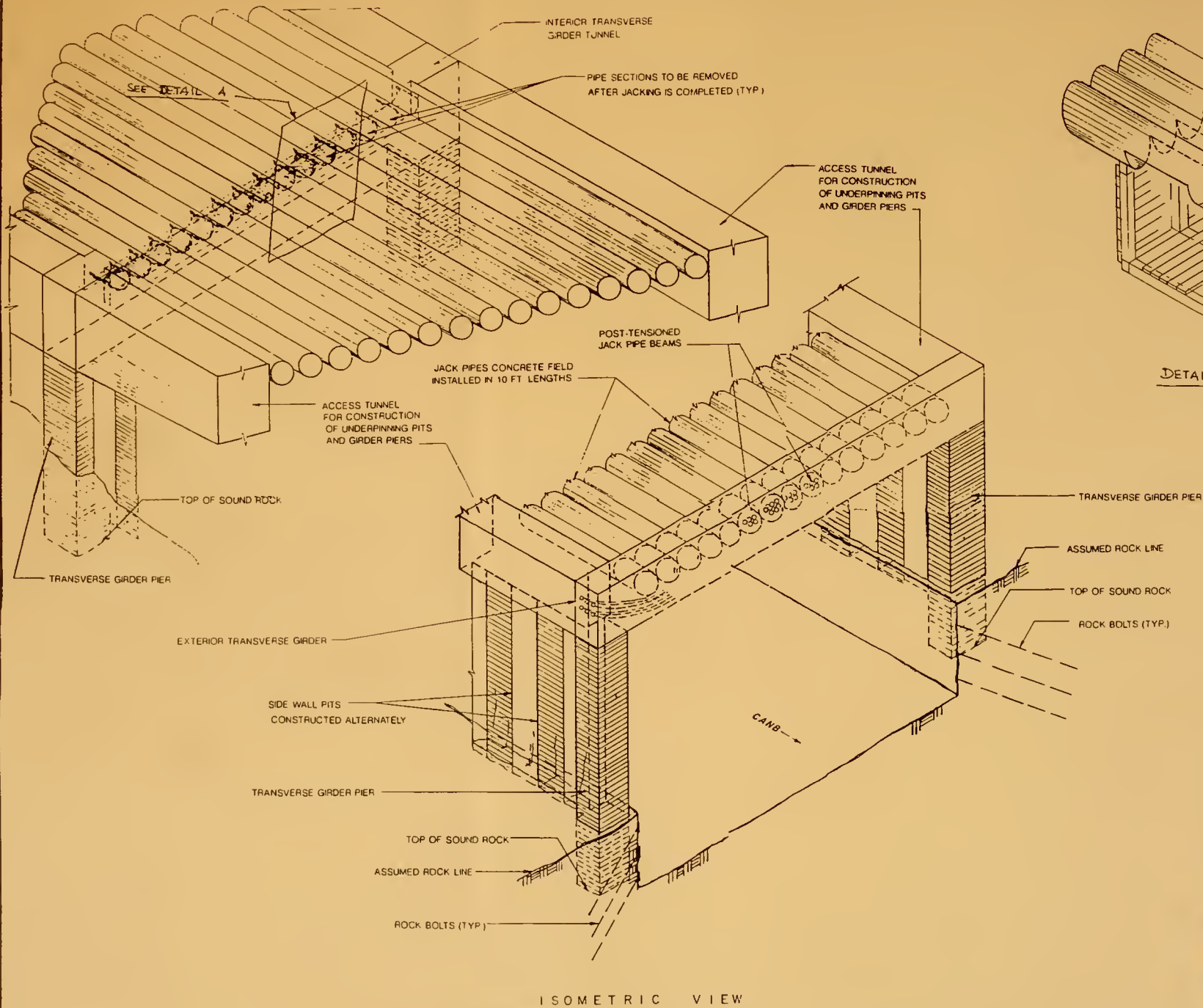
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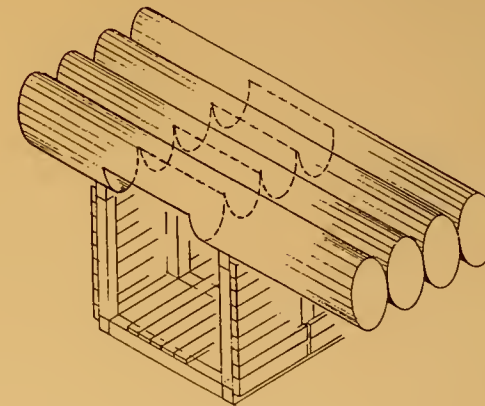
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BECHTEL/PARSONS BRINCKERHOFF			MANAGEMENT CONSULTANTS		
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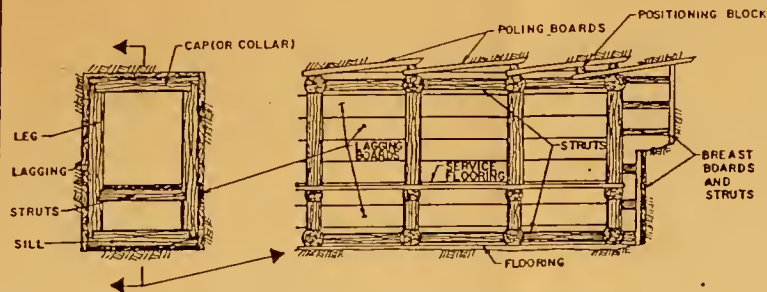
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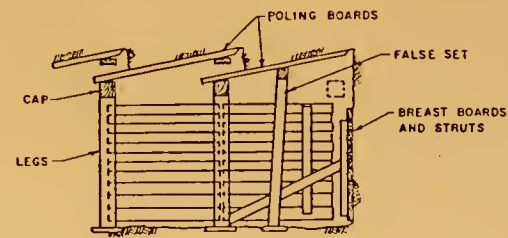
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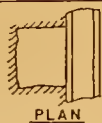
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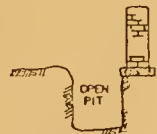
SQUARE SET



USE OF FALSE SET

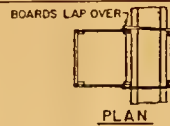


PLAN



ELEVATION

FIG. 1 DIGGING APPROACH PIT

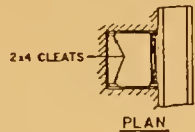


PLAN



ELEVATION

FIG. 3 PIT UNDER FOOTING EXCAVATED AND SHEETED



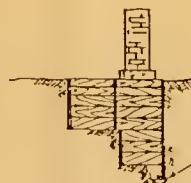
PLAN



ELEVATION

FIG. 2 APPROACH PIT SHEETED

TYPICAL EXAMPLE OF SINKING UNDERPINNING PITS



ELEVATION

FIG. 4 PIT UNDER FOOTING BEING SUNK

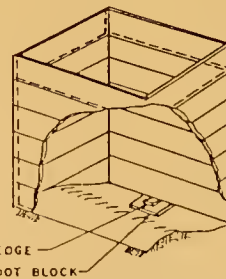
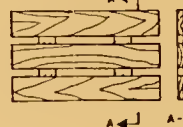
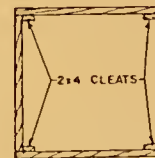


FIG. 1 SHOWING HOW PIT BOARDS ARE SET

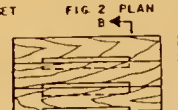


A-A

FIG. 3 LOUVRES, TYPE WITH CLEATS BETWEEN



NEXT SET OF BOARDS REVERSED



B-B



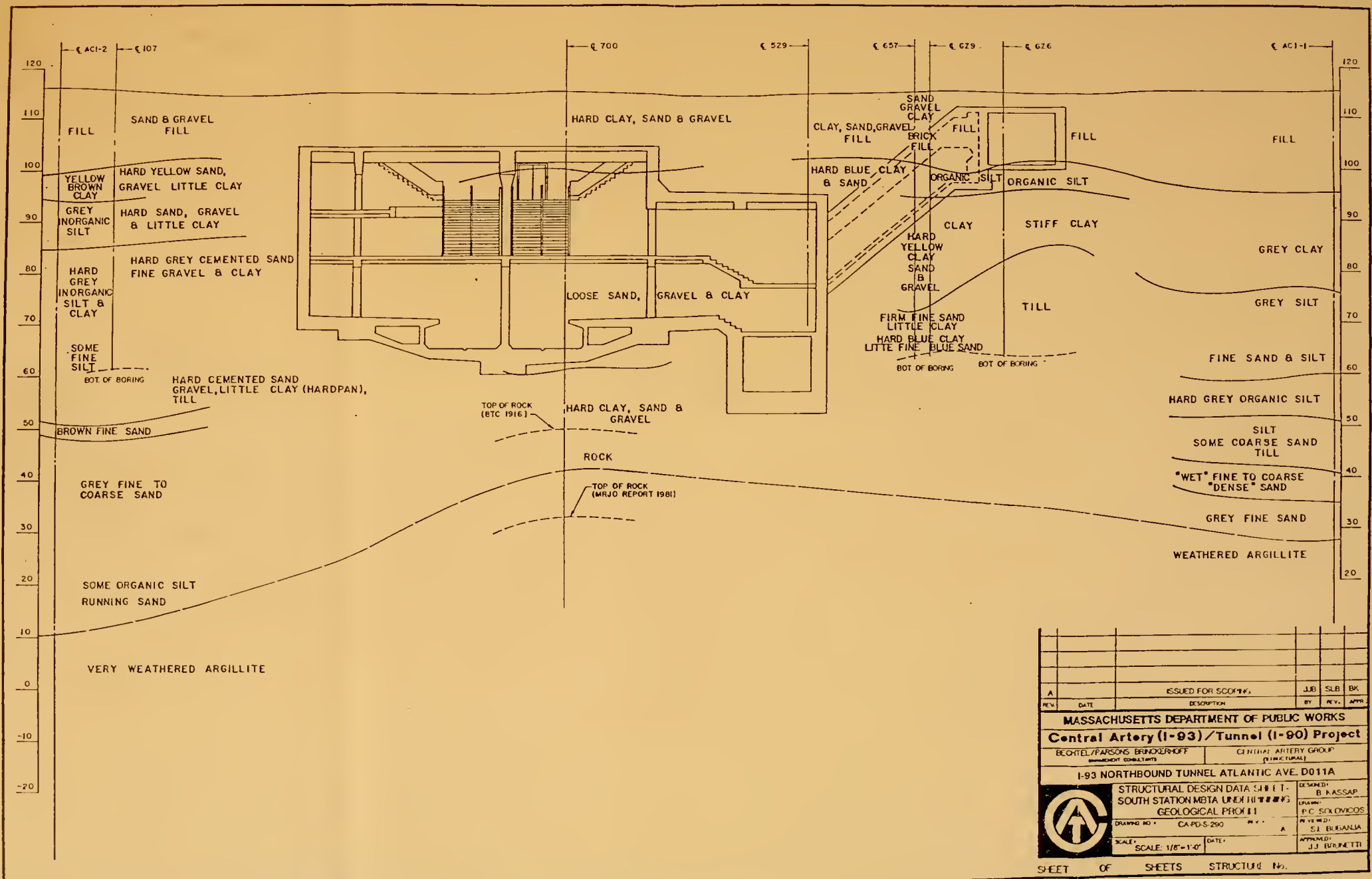
FIG. 4, LOUVRES, TYPE WITH NOTCHES CUT IN BOARD

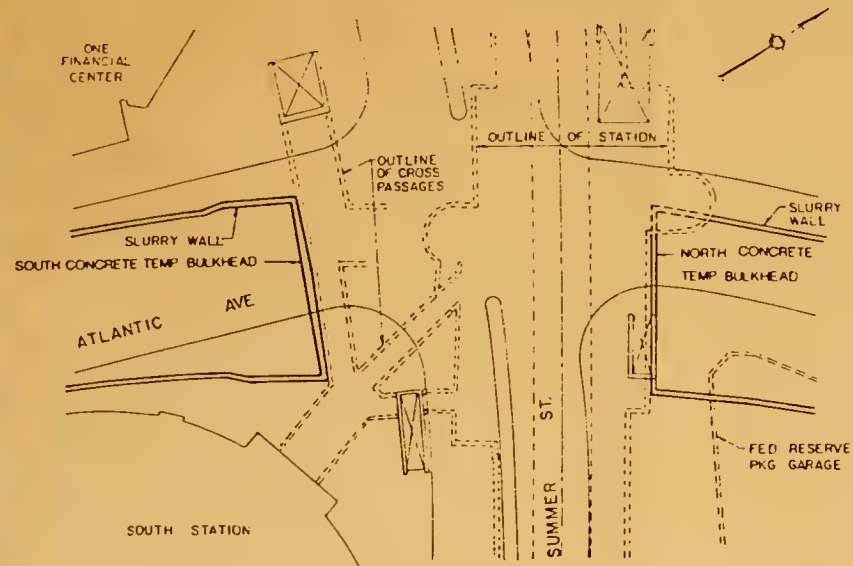
HORIZONTAL OR BOX SHEETING



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				J.J. BRUNETTI

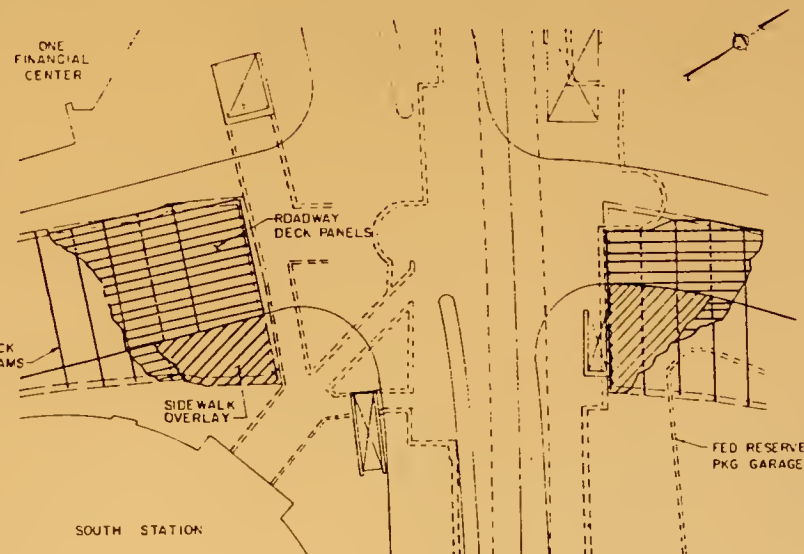
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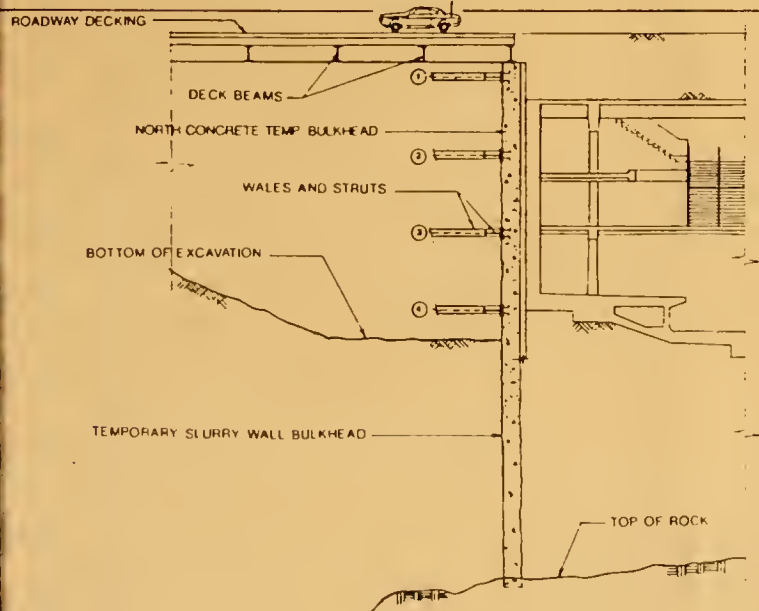
STAGE 1

INSTALL MONITORING DEVICE IN STATION AND AT STREET SURFACE,
AND INSTALL SLURRY WALLS NORTH AND SOUTH OF SUMMER STREET



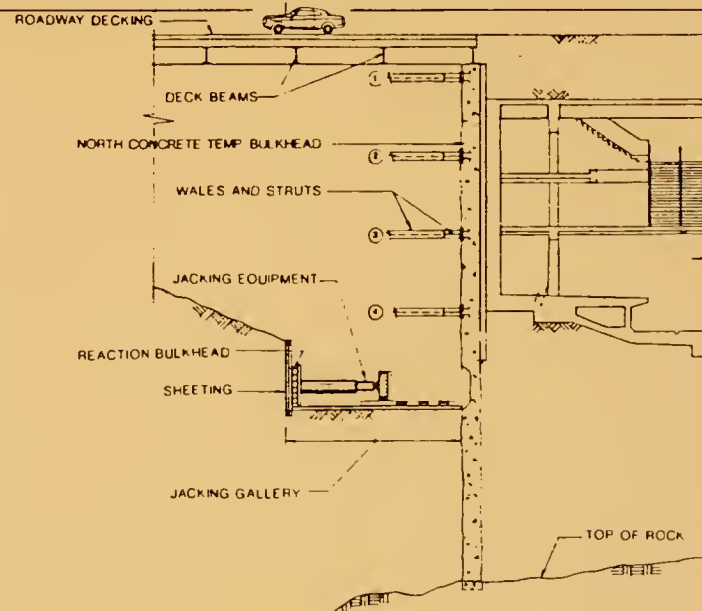
STAGE 2

INSTALL DECK BEAMS, DECKING, UTILITY SUPPORT/RELOCATION,
AND MAINTAIN TRAFFIC BY STAGING AND ON "OFF-HOURS" WORK



STAGE 3

EXCAVATE THROUGH DECK OPENINGS TO STRUT LEVEL NO. 4 NORTH AND SOUTH OF THE STATION ADJACENT
TO THE TEMPORARY CONCRETE SLURRY WALL BULKHEADS AND INSTALL ALL STRUTS AND WALES



STAGE 4

CONSTRUCT SHEETED JACK PIT GALLERY IN THE OPEN CUT
NORTH OF THE TEMPORARY CONCRETE SLURRY WALL BULKHEAD



STAGES OF CONSTRUCTION

1. INSTALL MONITORING DEVICES IN STATION AND AT STREET SURFACES, AND INSTALL SLURRY WALLS NORTH AND SOUTH OF SUMMER STREET.
2. INSTALL DECK BEAMS, DECKING, UTILITY SUPPORT/RELOCATION, AND MAINTAIN TRAFFIC BY STAGING AND ON "OFF-HOURS" WORK.
3. EXCAVATE THROUGH DECK OPENINGS TO STRUT LEVEL NO. 4, NORTH AND SOUTH OF THE STATION ADJACENT TO THE TEMPORARY CONCRETE SLURRY WALL BULKHEADS AND INSTALL ALL STRUTS AND WALES.
4. CONSTRUCT SHEETED JACK PIT GALLERY IN THE OPEN CUT, NORTH OF THE TEMPORARY CONCRETE SLURRY WALL BULKHEAD.
5. RISE TUNNELS (SQUARE SETS) FOR ACCESS TO THE SIDE WALL CONSTRUCTION, GIRDER PIER PITS AND THE TRANSVERSE GIRDER TUNNELS.
- 6a. PENETRATE CONCRETE SLURRY WALL BULKHEADS FROM THE NORTH SIDE AND BEGIN PIPE JACKING SEQUENCE, EXITING AT THE SOUTH CONCRETE BULKHEAD.
- 6b. CONSTRUCT GIRDER BEAM PIER TO SOUND ROCK AND CONSTRUCT THE ALTERNATE PIT WALLS CONCURRENTLY WITH THE PIPE JACKING OPERATION.
7. RISE AND CONSTRUCT THE CROSS GIRDER TUNNELS USING THE PREVIOUSLY JACKED PIPES TO ACT AS THE ROOF OF THE TUNNEL. REMOVE THE LOWER SECTION OF THE PIPE TO THE SPRINGLINE. THIS WILL PROVIDE A "BARREL ARCH" ROOF. CLEAN JACKED PIPES, COMPLETE GROUTING, SET END PLATES, WIRE STRAND, PLACE CONCRETE, CURE AND POST-TENSION.
8. COMPLETE CONSTRUCTION OF GIRDER PIERS, INTERIOR CROSS GIRDERS AND PIT WALLS. FORM EXTERIOR CARRIER GIRDERS, PLACE STEEL STRAND, CONCRETE, CURE AND POST-TENSION.
9. FORM AND PLACE CONCRETE FOR SIDEWALL EXTENSIONS AND CURB. EXCAVATE SOIL BENEATH JACKED PIPE BEAMS TO THE TOP OF ROCK AND BRAY THROUGH THE BALANCE OF THE CONCRETE SLURRY WALL BULKHEAD AND REMOVE.
10. BEGIN ROCK REMOVAL TO SUBGRADE USING NON-EXPLOSIVE METHODS. INSTALL REQUIRED RIF-PILOTS.
11. CONSTRUCT CENTRAL ARTERY NORTHWARD.
12. BACKFILL/RESTORE UTILITIES, REMOVE DECKING AND DECK BEAMS, AND REPAVE ADJOINING STREETS.

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REV	DATE	DESCRIPTION	BY	REV.	APP.

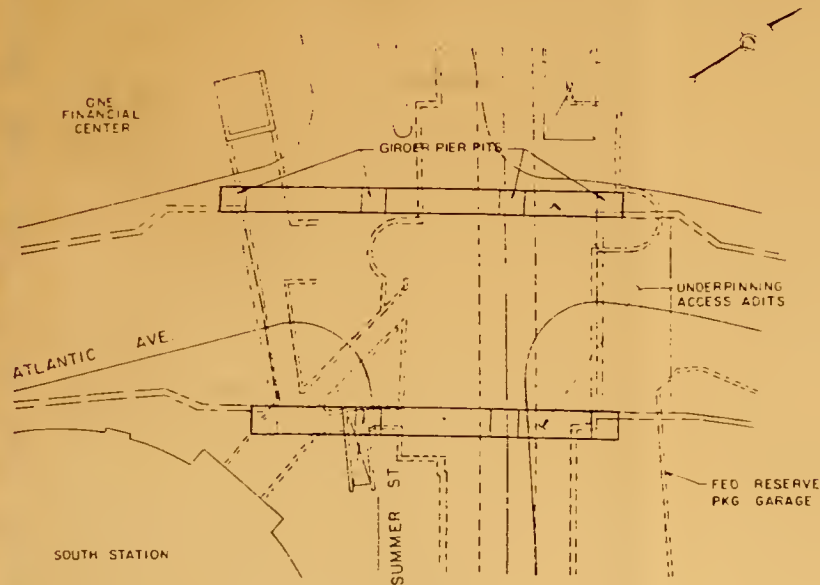
MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

Central Artery (I-93) / Tunnel (I-90) Project

BECHTEL/PARSONS BRINCKERHOFF CENTRAL ARTERY GROUP
MEMORANDUM CONSULTANT (STRUCTURAL)

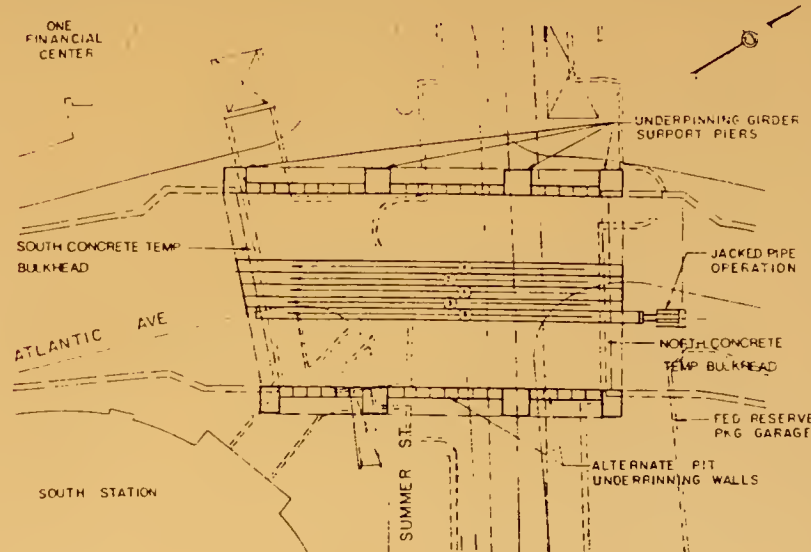
I-93 NORTHBOUND TUNNEL ATLANTIC AVE. D011A

	STRUCTURAL DESIGN DATA SHEET -		DESIGNED
	SOUTH STATION MBTA UNDERPASSING		B. KASSAP
	STAGES OF CONSTRUCTION SH. 1		DRAWN
	DRAWING NO. CA-PDS 291		P.C. SOLOVICOVS
SCALE	SCALE NONE	REV. A	REVIEWED
			S.I. BUBANJA
			APPROVED
			J.J. BRUNETTI



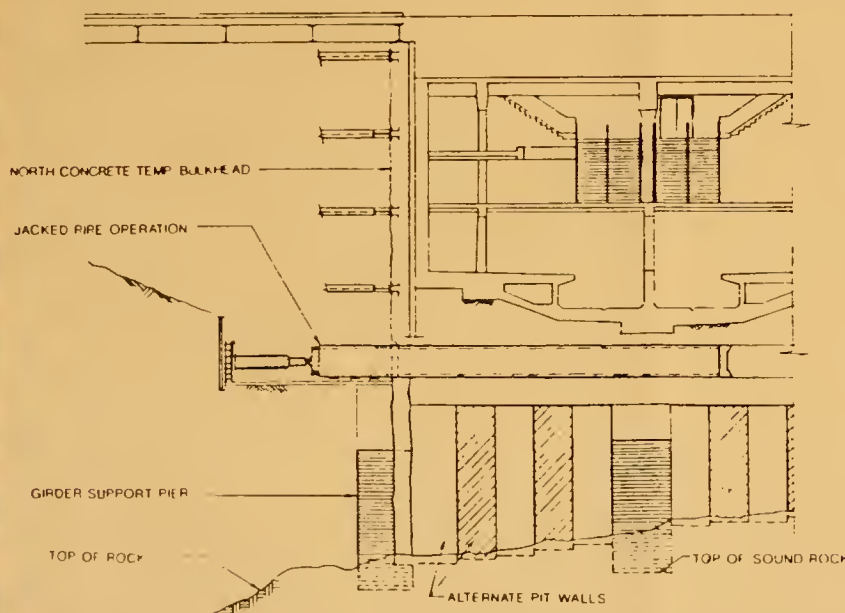
STAGE 5

MINE TUNNELS (SQUARE SETS) FOR ACCESS TO THE SIDE WALL CONSTRUCTION, GIRDER PIER PITS AND THE TRANSVERSE GIRDER TUNNELS



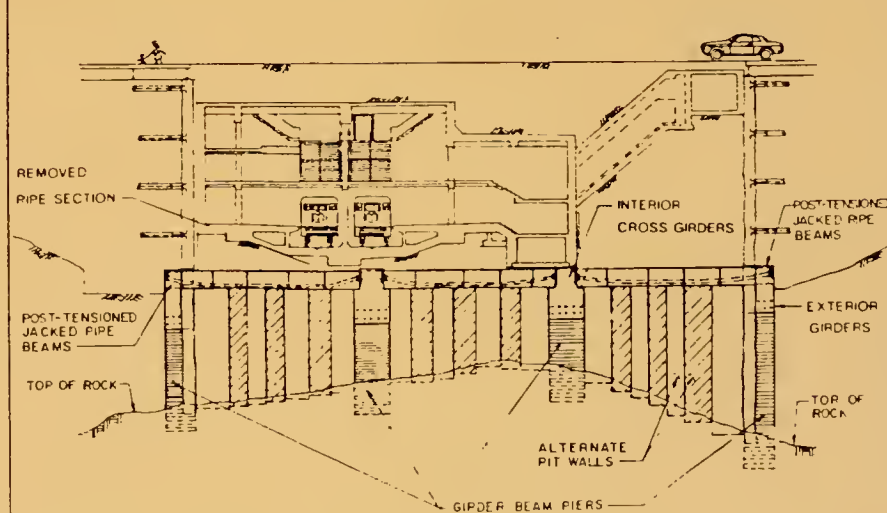
STAGE 6a

PENETRATE CONCRETE SLURRY WALL BULKHEAD FROM THE NORTH SIDE AND BEGIN PIPE JACKING SEQUENCE, EXITING AT THE SOUTH CONCRETE BULKHEAD



STAGE 6b

CONSTRUCT GIRDER BEAM PIERS TO SOUND ROCK AND CONSTRUCT THE ALTERNATE PIT WALLS CONCURRENTLY WITH THE PIPE JACKING OPERATION



STAGE 7

MINE AND CONSTRUCT THE CROSS GIRDER TUNNELS USING THE PREVIOUSLY JACKED PIPES TO ACT AS THE ROOF OF THE TUNNEL. REMOVE THE LOWER SECTION OF THE PIPE TO THE SPRINGLINE. THIS WILL PROVIDE A "BARREL ARCH" ROOF. CLEAN JACKED PIPES, COMPLETE GROUTING SET END PLATES, WIRE STRAND, PLACE CONCRETE, CURE AND POST-TENSION.



STAGES OF CONSTRUCTION

1. INSTALL MONITORING DEVICES IN STATION AND AT STREET SURFACES, AND INSTALL CURB WALLS NORTH AND SOUTH OF SUMMER STREET
2. INSTALL DECK BEAMS, DECKING, UTILITIES SLOTTED RELOCATION AND MAINTAIN TRAFFIC BY STAGING AND ON PLYTHROST WIRE
3. EXCAVATE THROUGH DECK OPENINGS TO ROCK LEVEL AND NORTH AND SOUTH OF THE STATION ADJACENT TO THE TEMPORARY CONCRETE SLURRY WALL BULKHEAD AND INSTALL ALL STRUTS AND WALES
4. CONSTRUCT SHEETED JACK PIT GALLERY IN THE OPEN CUT, NORTH OF THE TEMPORARY CONCRETE SLURRY WALL BULKHEAD
5. MINE TUNNELS (SQUARE SETS) FOR ACCESS TO THE SIDE WALL CONSTRUCTION, GIRDER PIER PITS AND THE TRANSVERSE GIRDER TUNNELS
- 6a. PENETRATE CONCRETE SLURRY WALL BULKHEADS FROM THE NORTH SIDE AND BEGIN PIPE JACKING SEQUENCE EXITING AT THE SOUTH CONCRETE BULKHEAD
- 6b. CONSTRUCT GIRDER BEAM PIERS TO SOUND ROCK AND CONSTRUCT THE ALTERNATE PIT WALLS CONCURRENTLY WITH THE PIPE JACKING OPERATION
7. MINE AND CONSTRUCT THE CROSS GIRDER TUNNELS USING THE PREVIOUSLY JACKED PIPES TO ACT AS THE ROOF OF THE TUNNEL. REMOVE THE LOWER SECTION OF THE PIPE TO THE SPRINGLINE. THIS WILL PROVIDE A "BARREL ARCH" ROOF. CLEAN JACKED PIPES, COMPLETE GROUTING SET END PLATES, WIRE STRAND, PLACE CONCRETE, CURE AND POST-TENSION
8. COMPLETE CONSTRUCTION OF GIRDER PIERS, INTERIOR CROSS GIRDERS AND PIT WALLS. FORM EXTERIOR CARRIER GIRDERS, PLACE STEEL STRAND, CONCRETE, CURE AND POST-TENSION
9. FORM AND PLACE CONCRETE FOR SIDEWALK EXTENSIONS AND CURB. EXCAVATE SOIL BENEATH JACKED PIPE BEAMS TO THE TOP OF ROCK AND BREAK THROUGH THE BALANCE OF THE CONCRETE SLURRY WALL BULKHEAD AND REMOVE
10. BEGIN ROCK REMOVAL TO SLOGRADE USING HIGH-EXPLOSIVE METHODS. INSTALL REQUIRED ROCKBOARDS
11. CONSTRUCT CENTRAL ARTERY NORTHBOUND
12. BACKFILL/RESTORE UTILITIES, REMOVE DECKING AND DECKBEAMS, AND REPAVE ADJACENT STREETS

REV	DATE	DESCRIPTION	BY	REV	APPROV
A	01/29/91	ISSUED FOR CONSTRUCTION	BA	SLB	JLR

MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

Central Artery (I-93) / Tunnel (I-90) Project

BECHTEL/PARSONS BRINCKERHOFF
IMMEDIATE CONSULTANTS

CENTRAL ARTERY GROUP
(STRUCTURAL)

I-93 NORTHBOUND TUNNEL ATLANTIC AVE. D011A

	STRUCTURAL DESIGN DATA SHEET	DESIGNED	B. PASSAP
	SOUTH STATION MBTA UNDERPINNING	DRAWN	P.C. SOLOWICK
	STAGES OF CONSTRUCTION SH. 2	REVIEWED	SL. HUBANIA
	DATE: SCALE: NONE	APPROVED	J.J. HUBANIA

STAGE 8

COMPLETE CONSTRUCTION OF GIRDER PIERS, INTERIOR CROSS GIRDERS AND PIT WALLS
FORM EXTERIOR CARRIER GIRDERS, PLACE STEEL STRAND, CONCRETE, CURE AND POST-TENSION

STAGE 9

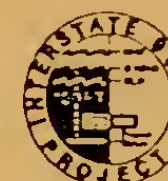
FORM AND PLACE CONCRETE FOR SIDEWALL EXTENSIONS AND CURE. EXCAVATE SOIL BENEATH JACKED PIPE BEAMS TO THE TOP OF ROCK AND BREAK THROUGH THE BALANCE OF THE CONCRETE SLURRY WALL BULKHEAD AND REMOVE

STAGE 10

BEGIN ROCK REMOVAL TO SUBGRADE USING NON-EXPLOSIVE METHODS
INSTALL REQUIRED ROCK BOLTS

STAGE 11

CONSTRUCT CENTRAL ARTERY NORTHBOUND:



STAGES OF CONSTRUCTION

1. INSTALL MONITORING DEVICES IN STATION AND AT STREET SURFACES, AND INSTALL SLURRY WALLS NORTH AND SOUTH OF SUMNER STREET.
2. INSTALL DECK BEAMS, DECKING, UTILITY SUPPORT/RELOCATION AND MAINTAIN TRAFFIC BY STAGING AND ON "OFF-HOURS" WORK
3. EXCAVATE THROUGH DECK OPENINGS TO STILT LEVEL NO. 4, NORTH AND SOUTH OF THE STATION ADJACENT TO THE TEMPORARY CONCRETE SLURRY WALL BULKHEADS AND INSTALL ALL BRUTS AND WALLS.
4. CONSTRUCT SHEETED JACK PIT GALLERY IN THE OPEN CUT, NORTH OF THE TEMPORARY CONCRETE SLURRY WALL BULKHEAD.
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- 6a. PENETRATE CONCRETE SLURRY WALL BULKHEADS FROM THE NORTH SIDE AND BEGIN PIPE JACKING SEQUENCE, EXITING AT THE SOUTH CONCRETE BULKHEAD.
- 6b. CONSTRUCT GIRDER BEAM PIERS TO SOUND ROCK AND CONSTRUCT THE ALTERNATE PIT WALLS CONCURRENTLY WITH THE PIPE JACKING OPERATION.
7. MINE AND CONSTRUCT THE CROSS GIRDER TUNNELS USING THE PREVIOUSLY JACKED PIPES TO ACT AS THE ROOF OF THE TUNNEL. REMOVE THE LOWER SECTION OF THE PIPE TO THE SPRINGLINE. THIS WILL PROVIDE A "BARREL ARCH" ROOF. CLEAN JACKED PIPES, COMPLETE GROUTING, SET END PLATES, WIRE STRAND, PLACE CONCRETE, CURE AND POST-TENSION.

8. COMPLETE CONSTRUCTION OF GIRDER PIERS, INTERIOR CROSS GIRDERS AND PIT WALLS. FORM EXTERIOR CARRIER GIRDERS, PLACE STEEL STRAND, CONCRETE, CURE AND POST-TENSION.
9. FORM AND PLACE CONCRETE FOR SIDEWALL EXTENSIONS AND CURE. EXCAVATE SOIL BENEATH JACKED PIPE BEARS TO THE TOP OF ROCK AND BRIEF THROUGH THE BALANCE OF THE CONCRETE SLURRY WALL BULKHEAD AND REMOVE.
10. BEGIN ROCK REMOVAL TO SUBGRADE USING POW-EXPLOSIVE METHODS. INSTALL REQUIRED ROCKBOLTS.
11. CONSTRUCT CENTRAL ARTERY WORTHBOUND.
12. BACKFILL/RESTORE UTILITIES, REMOVE DECKING AND DECKBEAMS, AND REPAVE ADJOINING STREETS.

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MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

Central Artery (I-93) / Tunnel (I-90) Project

BECHTEL/PARSONS BRINCKERHOFF MANAGEMENT CONSULTANTS	CENTRAL ARTERY GROUP (STRUCTURAL)
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F93 NORTHBOUND TUNNEL ATLANTIC AVE. D011A

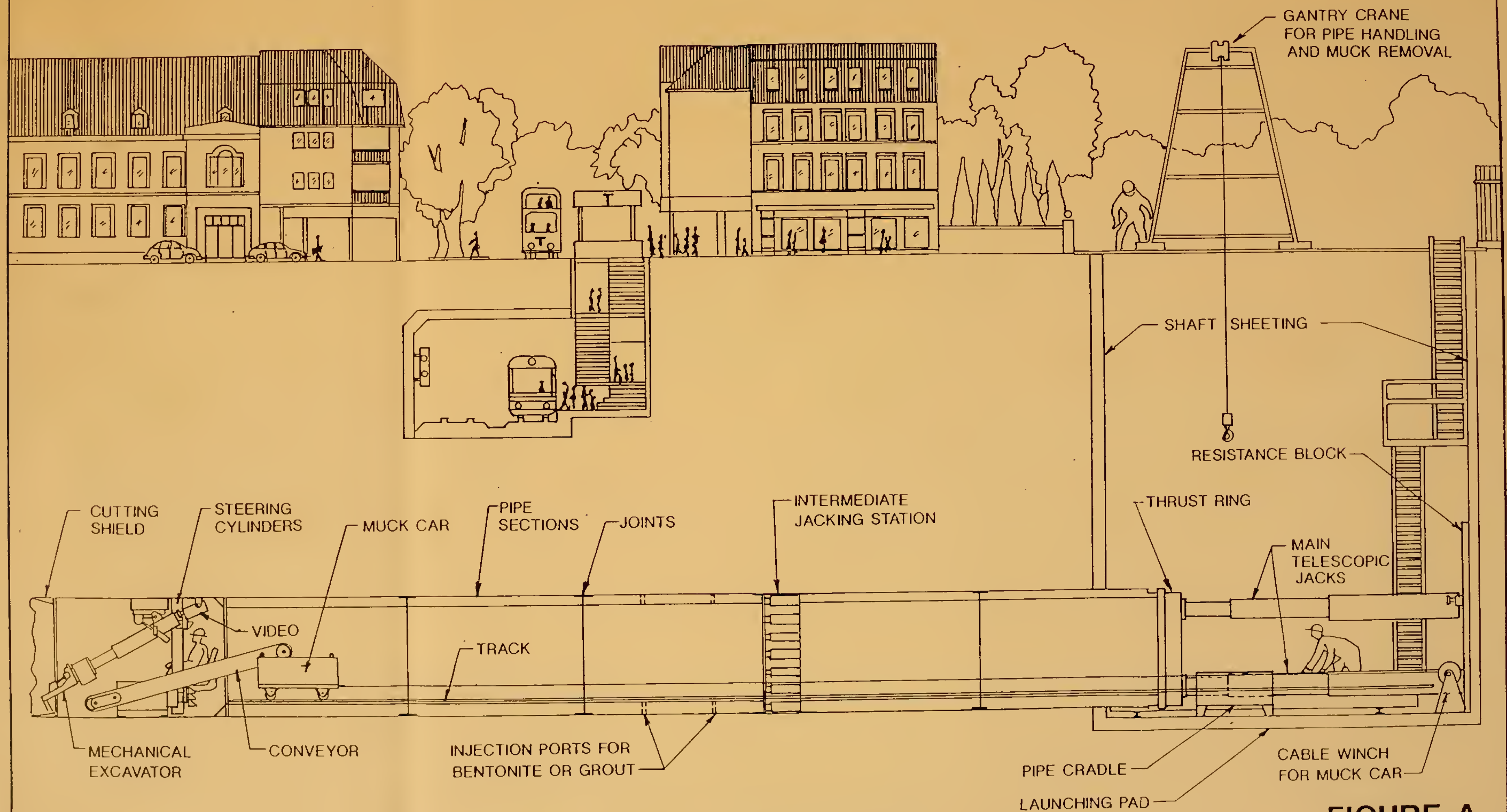


STRUCTURAL DESIGN DATA SHEET
SOUTH STATION MBTA UNDERPINNING
STAGES OF CONSTRUCTION SH. 3

DRAWING NO. CA-PD-S 293

SCALE: SCALE NONE

DESIGNED:	B KASSAP
DRAWN:	P C SOLOVICKS
REVIEWED:	SI BUBANJA
APPROVED:	JJ BRUNETTI



TYPICAL ELEMENTS OF JACK-PIPE TUNNELING

FIGURE A

UNDERGROUND CONSTRUCTION OF THE ROOF SLAB BY PIPE JACKING

Principle

Tubes of great diameter (1,2 m to 2 m) are driven into the ground, one next to the other, from a construction shaft or a gallery.

Reinforcements are placed and concrete is cast in the tubes.

After applying a sealing joint between the tubes, the

structure thus formed can function as a roof slab after partial digging and building supporting walls by the lined excavation method.

By digging under this slab, a volume is obtained, from which it is possible to proceed to further excavation in security.

Execution

According to the volume available (gallery or shaft) to start driving the tubes, these will consist of sections of 1 m to 5 m. The front edge of each section is equipped with a cutting shoe (to attack the soil) allowing the tube to be jacked into the soil.

The first section is placed on a supporting structure equipped with a pressure distribution ring and driven into the soil by means of hydraulic jacks with slidable pistons. The second section is brought to the height of the first one and coupled to it by means of a steel ring. A foam rubber sealing joint is placed between the tubes.

When a whole tube has been driven next to the preceding

one, cement is injected into the interval (10 to 20 cm). As driving progresses, the soil is drawn manually and evacuated by wagons. Control measurements are done steadily in view of detecting and correcting possible vertical or horizontal deviations.

The allowance in tube diameter is very restricted in view of reducing the resistance due to salient soil elements as far as possible and preventing settings.

The materials used hitherto were generally asbest-cement, concrete or steel tubes. Ordinary steel reinforcements or prestressed elements may be used.

To ensure a good filling liquid concrete has been used.

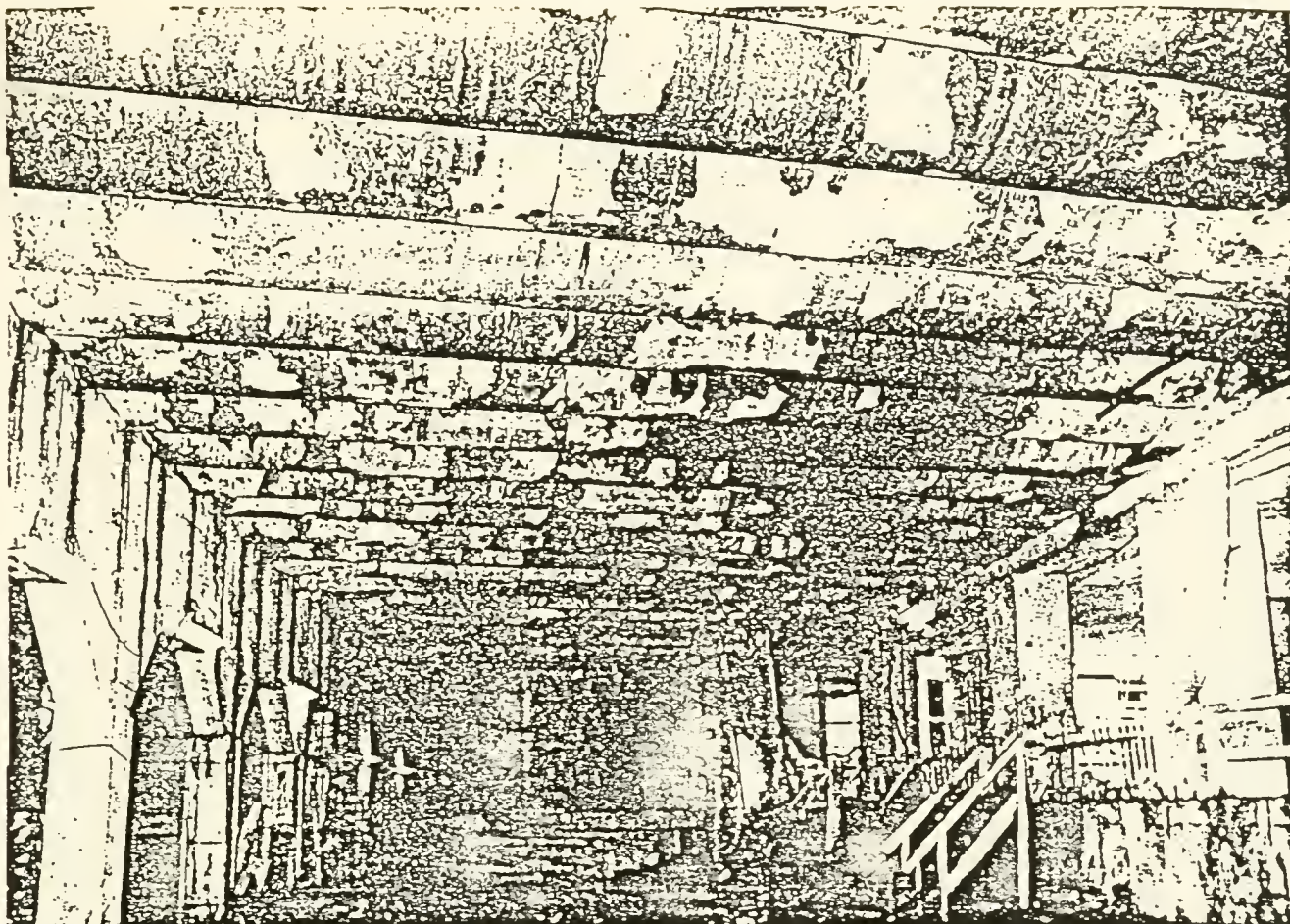
Appliances

As this technique is quite new a first test slab was made in the second half-year 1975. This slab is a constructional element of the transfer station KONINGIN ASTRID.

The test involved jacking a series of 6 parallel tubes over a length of 30 m, at 1,20 m to 1,50 m depth under the street level.

This test was quite satisfactory and it was decided definitely to build the transfer station KONINGIN ASTRID by the tube jacking method. The constructional works comprise four underground levels:

- the 1st underground level comprises the 1st ticket-hall and, next to it, at the same level, the station platforms on the Gemeentestraat - Camotstraat line;
- the 2nd level comprises the 2nd ticket-hall, situated along the west side of Koningin Astridplein and under the Van Wesenbkestraat;
- platforms 1 and 2 of the axis parallel to the Van Wesenbkestraat are located respectively on levels 3 and 4.



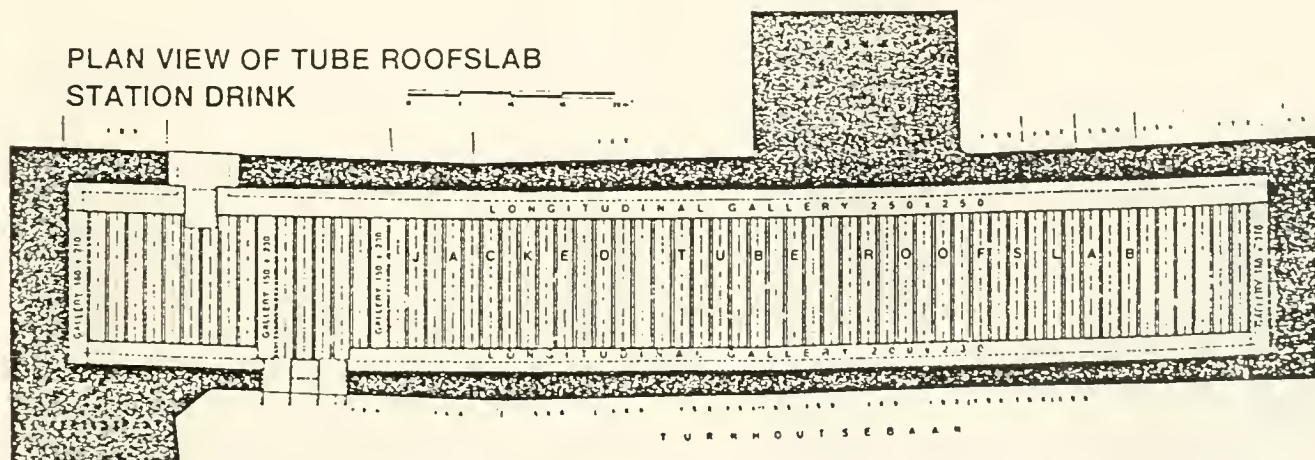
Transfer station Koningin Astrid

Underground roof slab consisting of driven asbest-cement tubes (\varnothing 1,20 m). On the left: the medial columns between the future tramway tracks on the line Koningin Astridplein - Franklin Rooseveltplaats. Contractor: C.E.I. S.A. - March 1979 PHOTO G. COOLENS N.V. Antwerpen

The construction of the main walls was begun on 15 March 1976. The underground roof slab consisting of 3112 m asbest-cement tubes was achieved in August 1977.

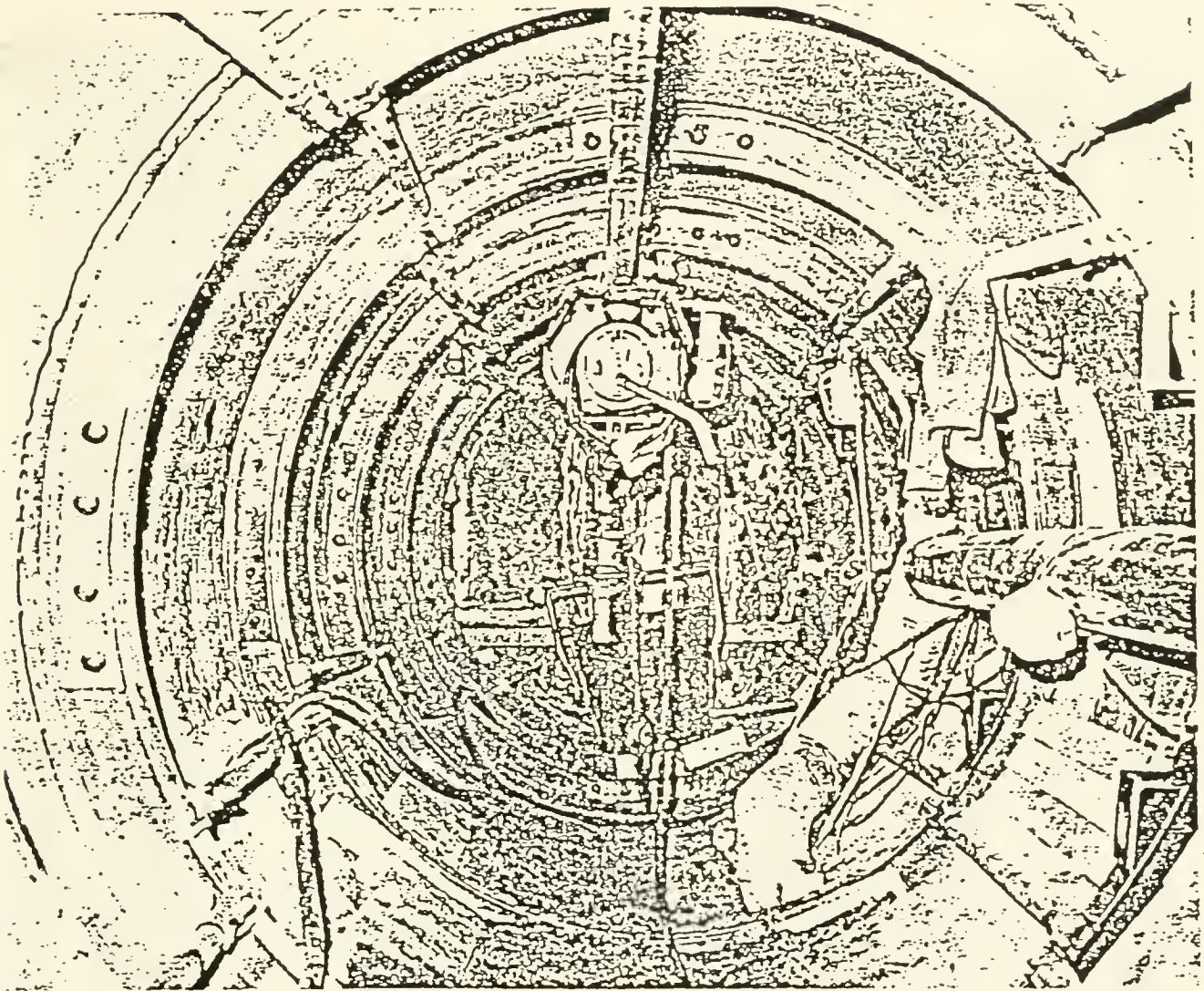
As this construction method gave full satisfaction it was decided to apply it to the construction of other stations and of some tunnels, with some improvements and adaptations gained from the first experience.

PLAN VIEW OF TUBE ROOFSLAB
STATION DRINK



For building the stations ZEGEL and DRINK, asbest-cement tubes of 1.5 m in diameter were driven from galleries of 2.5 m x 2.5 m in section.

The tube sections were 1 m long. After achieving the tubes, a tight coating is applied to the joints and the outer side of the tubes are injected. About 1.660 m tube of 1.5 m in diameter have been driven for the two stations.



Station Carnot

Underground construction - steel tube \varnothing 1,80 m with reinforcement rings. Construction of the station wall from this tube by the lined excavation method.

Contractor: Pieux Franki S.A.

September 1978

PHOTO G. COOLENS N.V. Antwerpen

Station Carnot

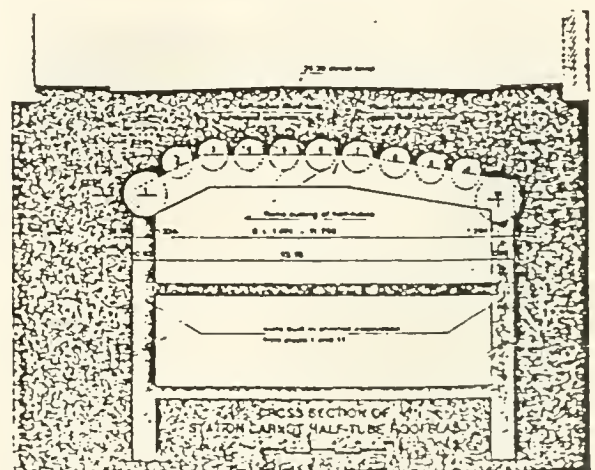
In this station a working volume was first formed under a cover consisting of steel tubes of 1,2 m in diameter, laid under the carriageway surfacing.

After driving the tubes, the upper half was filled with concrete and the lower half was removed.

Under this cover the transverse gallery was driven further. From there, longitudinal steel tubes were driven, the inner tubes being 1,2 m and the outer ones 1,8 m in diameter.

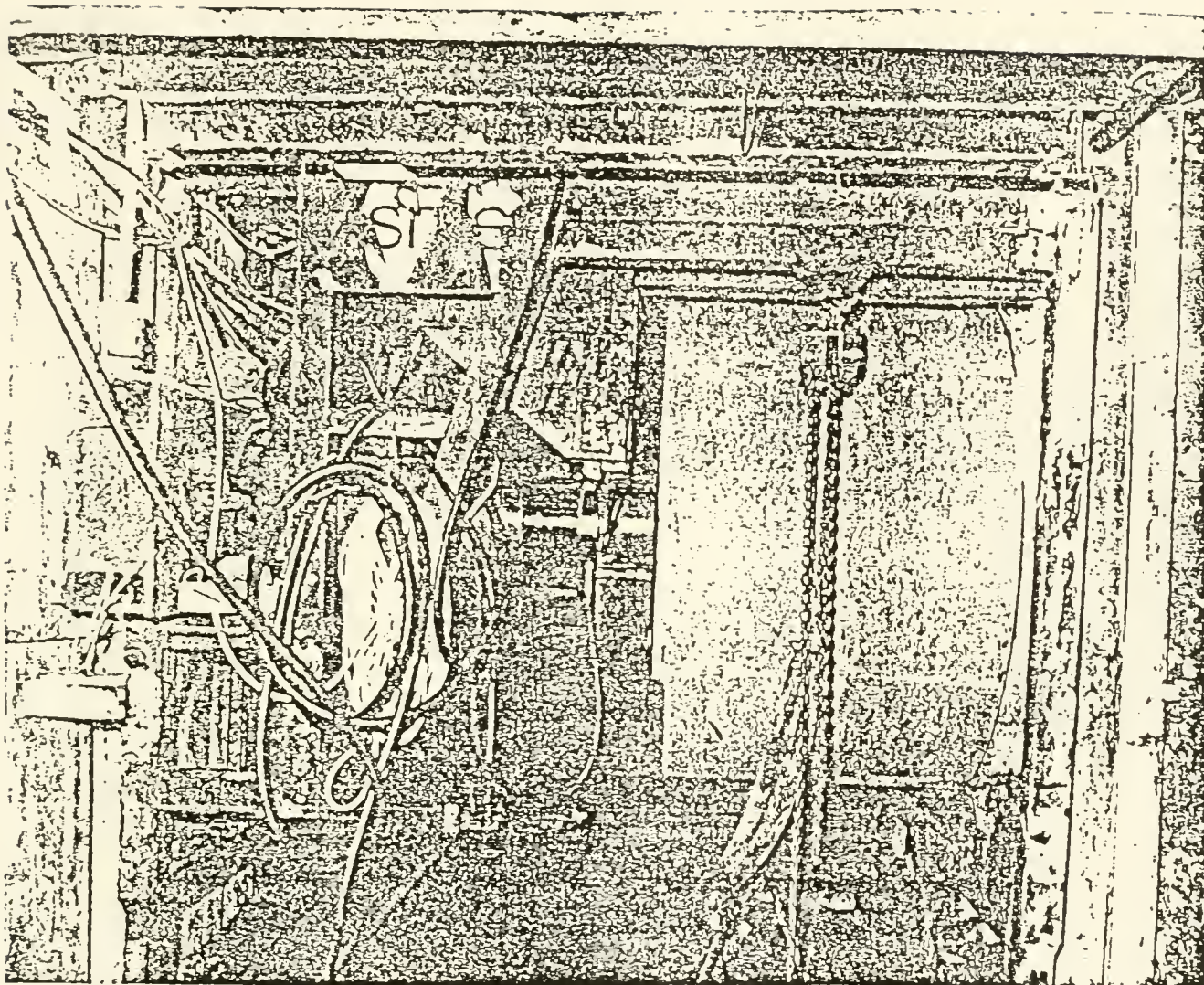
To obtain the tunnel section required in the middle and to keep at a good distance from the sewer pipes, the tubes were placed to form a sort of vault. Here too the tubes were filled with concrete and the lower half of the tubes was removed (see section).

The long lateral tubes of 1,8 m are opened in their lower part, supported by frames (see picture) and from there the sheeted excavations for the walls are dugged and concreted.



On the whole 192 m tubes of 1,8 m and 1.272 m tubes of 1,2 m in diameter have been driven, with a maximum continuous length of 78,3 m.

7.57F



Station Morckhoven

Underground construction of the cover slab.

Asbest-cement pipes (O 1.60 m, length 1 m) are driven from a gallery (2.5 m x 2.5 m) at 3 m depth under the road surfacing

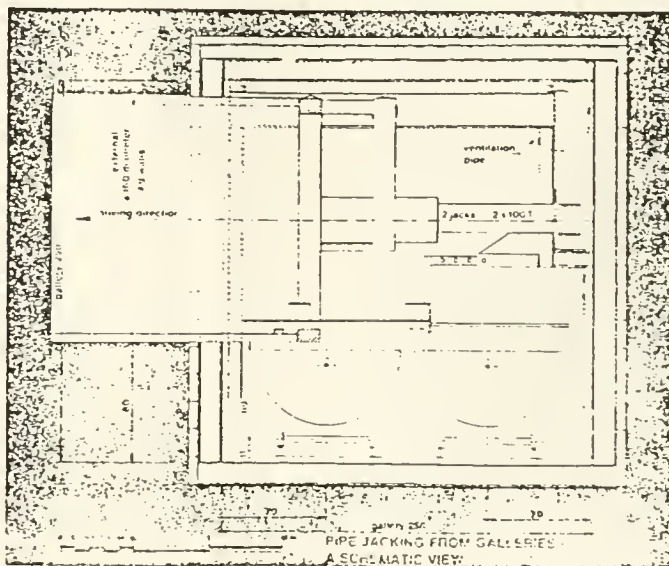
Contractor: Joint Venture MECOMA

March 1979

PHOTO G. COOLENS N.V. Antwerpen

The experience gained with this new construction method is quite positive, as well in regard to timing as to feasibility.

During driving, even at small depth, the traffic was never interrupted and the users of the road had no inkling of the work being done under the street. The method is being improved and subjected to further adjustment, thus presenting a bright guarantee for future.

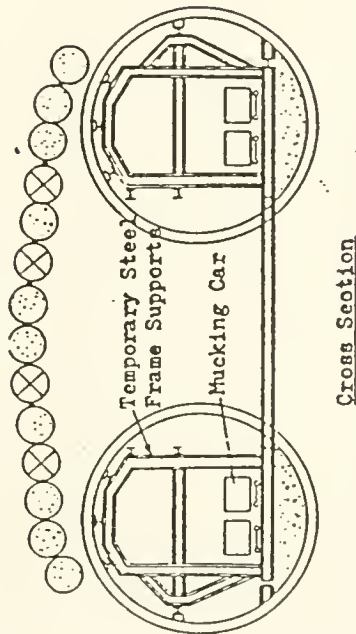


Installation of Strut at Lowest Level

In order to prevent horizontal movement of the tunnels due to the lateral force acting on side walls of the tunnel during the excavation the portion between two parallel tunnels, a three step strutting had been provided. The strut at the lowest level had been pushed towards another tunnel while the pipe-roof was being installed, then reinforced concrete was placed at the invert part in order to reinforce the lower part of the segments.

Erection of Temporary Steel Frame Supports

In order to minimize the deformation of tunnel sections due to excavation of the portion between two parallel tunnels, temporary steel frame supports had been erected inside the tunnels, providing the necessary working space, as shown in Fig. 5.



(A) Erection of Temporary Steel Frame Supports inside Tunnels.

Fig. 5— Construction Procedures (b)

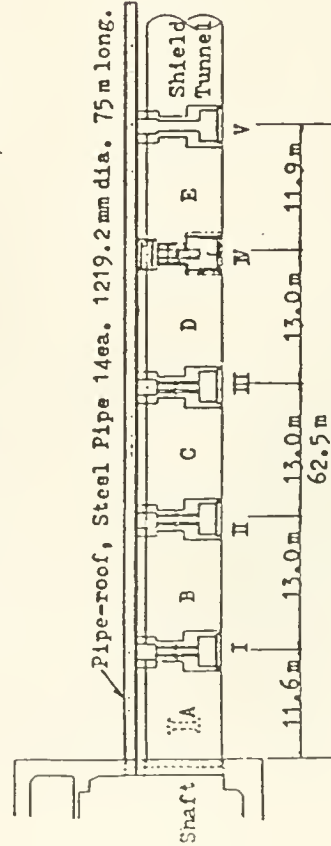
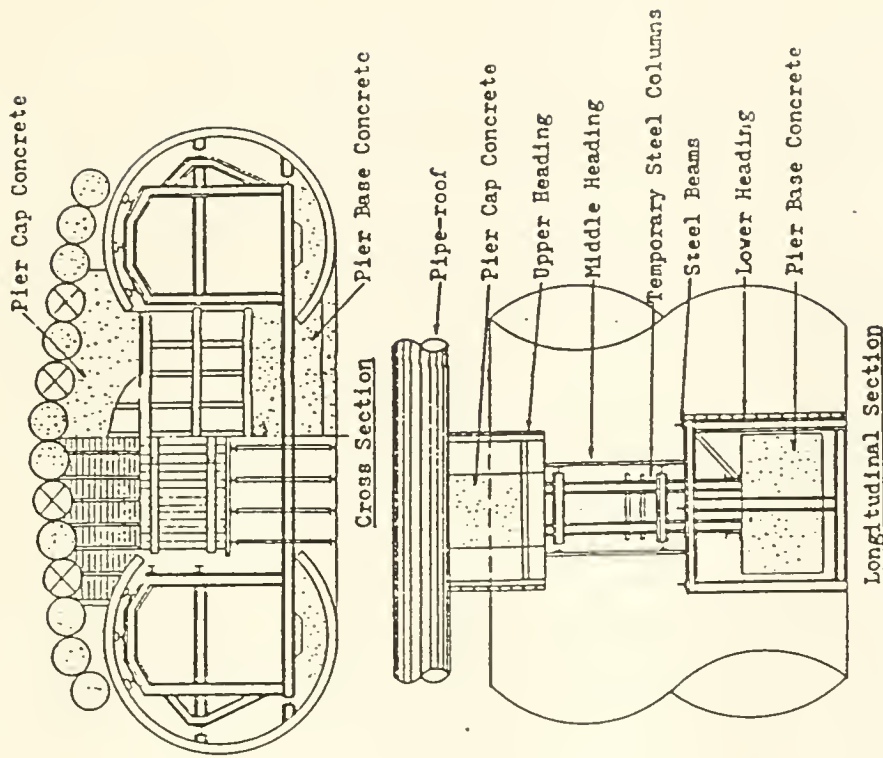


Fig. 6— General Layout of Piers

Placement of Piers for Pipe-roof Support

After the erection of steel frame supports, five piers were constructed to support the pipe-roof by five spans, as illustrated in Fig. 6.



(5) Horizontal Jacking of Steel Beams along Top of Lower Heading.

(6) Excavation of Lower Heading.

(7) Placing Pier Base Concrete.

(8) Excavation of Upper Heading.

(9) Erection of Middle Heading.

(10) Erection of Temporary Steel Columns and Placing Pier Cap Concrete.

Note: Pier Construction Stage-1. — Piers I, III and V.

Pier Construction Stage-2. — Piers II and IV.

Fig. 7— Construction Procedures (c)

Two-thirds of Taiwan's 36 000km² is mountainous, with the highest peak rising to 4000m. In urban areas, tunnelling is required to minimise disruption to already congested areas.

That Taiwan has the money to pay for the programme there is no doubt, but transforming the political will and capital allocation into reality will be extremely challenging. The path is strewn with problems. Legal and technological obstacles, together with labour limitations, are compounded by extremely difficult geological conditions.

The Taiwanese have undertaken major tunnelling projects in the past. There are several hydroelectric schemes in existence and some 30km of the 80km-long northern and eastern section of the round island railway line, completed about ten years ago, is in tunnel, the longest being 8km. In urban areas, the new central railway station in Taipei with its underground approaches and underground platforms built by cut-and-cover is a marvellous achievement, as is the recently opened immersed tube road tunnel in Kaohsiung harbour and the major road underpass tunnelled under the city's railway station (Fig 2).

Call to internationals

Much of the engineering for these schemes and all the construction work has been undertaken by local companies. Many local engineers have studied abroad, particularly in the United States, and domestic engineering skills are high. But the domestic capability is not adequate for the programme planned for the next ten years. Consulting engineering companies are already feeling the pressure of a much increased work load and are recruiting new staff constantly. Even so, foreign assistance is required and must be sought in both consulting engineering and construction to introduce the most up-to-date and effective tunnelling designs and practices that the world has to offer. These will be needed to fulfill the current ambitious plans.

There are, however, several factors that should be considered by foreign consultants and contractors who are interested in the Taiwanese market. Joint ventures with local counterparts are strongly encouraged for effective transfer of technology but this can be difficult since the domestic capacity is still in its infancy, particularly in the tunnelling field.

Sinotech, the autonomous multi-disciplined consulting organisation established about 20 years ago under the auspices of the Ministry of Economic Affairs, is the country's best known and most experienced consulting engineer.

RSEA is the largest and most experienced contractor. Originally formed by retired servicemen, RSEA still takes on retired armed forces personnel to increase the labour force assigned by the

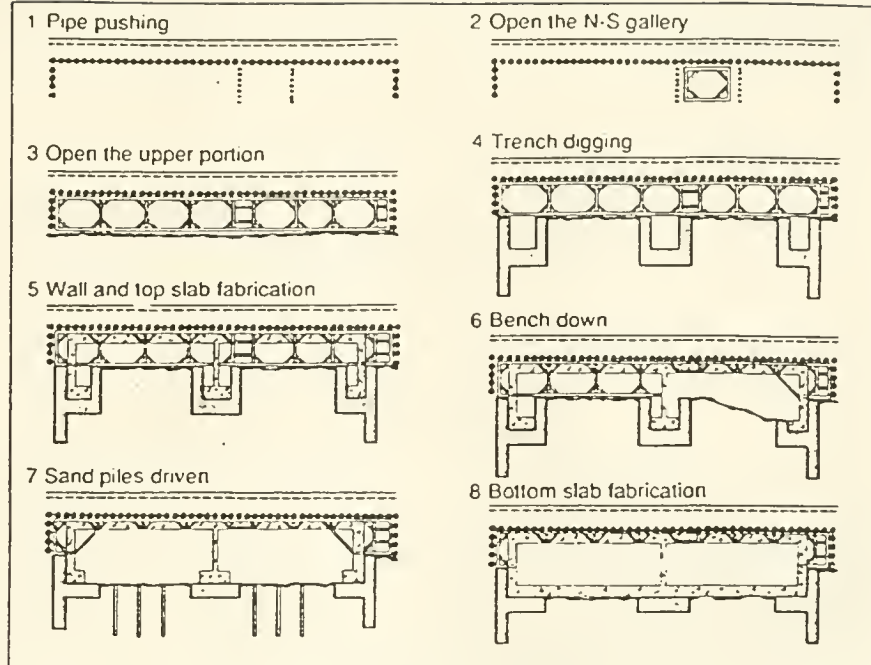


Fig 2. A total of 59, 600mm diameter \times 81m-long pipes were jacked underneath the main railway station to complete this critical section of the 864m-long road underpass in Kaohsiung. The project was completed in just over two years in 1987. Bache Soletanche of France provided slurry wall expertise in the open cut sections.

government under its vocational assistance scheme or required by RSEA to complete current projects. RSEA in return is given the privilege of negotiating public works contracts, particularly those requiring particular expertise, instead of going through a competitive bid process. The final price, however, must be within the budget set by the government.

This has created a particular problem, especially on tunnelling projects. Once the contract is agreed, there is little room for change, regardless of the actual working conditions. The government expects the work to be completed within the budgeted price. There is extremely tight control over contract changes. The consultant is totally responsible for the design and the chosen tunnelling method, and the contractor is responsible for the extra time, labour and materials that may be required due to changes in ground conditions. Obvious delays do lead to renegotiation but these are also said to be long and hard.

As a result, many tunnelling contracts, which are hard to predict in cost terms and involve a high degree of risk, are often far from making a profit, and instead turn in substantial losses.

Wanted: tunnellers

Among Taiwan's immediate problems is a chronic shortage of labour. It is not so much that there is little man power available but more that there are few willing to work in the construction industry and more particularly in the tunnelling industry. The few construction workers that there are prefer to work in urban areas and on building sites rather

than underground in tunnelling projects which are often remote. Private enterprise building sites in town often pay higher wages than can be earned on public infrastructure project works, although rates of pay on these are comparable to those earned by tunnel workers in the US and Europe.

There are also easier ways of earning money in Taiwan, including investing in the buoyant Taiwanese stock market. Like many oriental peoples, the Taiwan Chinese are industrious and shrewd in business. Many ordinary people have become affluent by investing in a stock market that is now considered by foreign analysts to be unrealistically high. Under these circumstances, labourers will only work on a casual basis to top up their spending money; it is very difficult to get them to stay with a project for a worthwhile length of time.

This creates severe problems. Training of new labour goes on constantly and after three or four weeks, workers will then leave either to be unemployed or else to work on a building project as a trained labourer for more money.

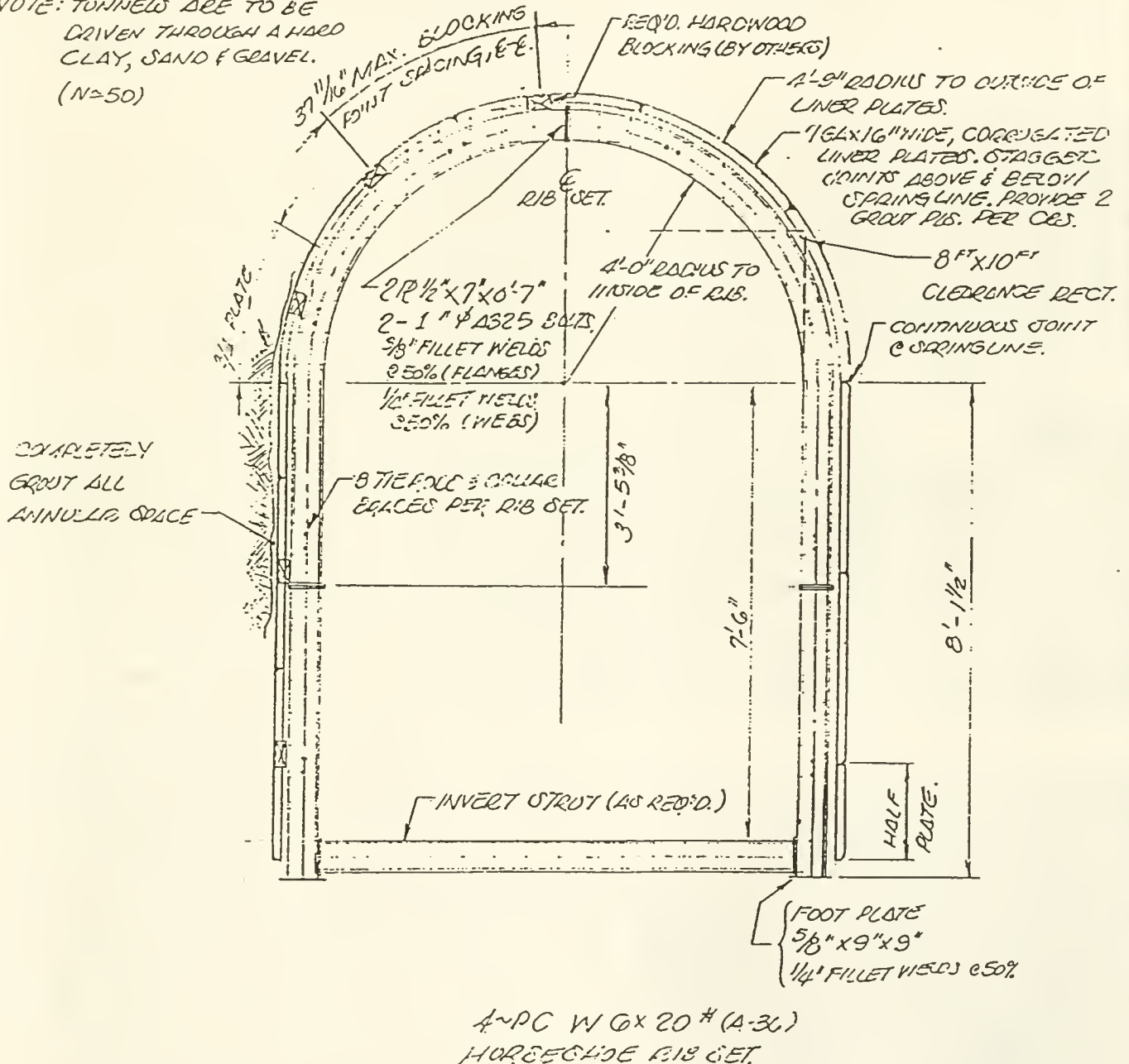
A possible solution to the problem is to import cheaper labour from countries such as Malaysia and Thailand but Taiwan has strict laws to prevent large-scale immigration. Ways of relaxing these laws to allow foreign workers in to complete a contract but to prevent them from taking up permanent residence in the more affluent society are being investigated. Professionals from other countries may obtain working visas for Taiwan but only under sponsorship from local agencies.

Under present circumstances, labour



PROPOSED TEMPORARY TUNNEL SUPPORT
SYSTEM FOR 8'x10' ACCESS TUNNELS
(LOCATED 3 1/2' - 4 1/2' BELOW EXISTING STATION).

NOTE: TUNNELS ARE TO BE
DRIVEN THROUGH A HARD
CLAY, SAND & GRAVEL.
(N=50)



(SCALE: 3/8" = 1'-0")

THIS SYSTEM CAN SAFELY SUPPORT
A UNIFORM LOADING OF APPROXIMATELY
3945 PCF WHEN INSTALLED AS SHOWN
WITH RIBS ON 4' CENTERS.

FIGURE B

• APR. 18, 1985 •

Jacked pipes form subway roof

Antwerp method avoids the disruption of cut-and-cover work

Albert Wittemans, director of the Antwerp metro authority, well remembers the fateful day in 1975 when Belgium's Minister of Transport told him that unless he could complete his 16.2-km system without continuing to use the cut-and-cover method that was disturbing traffic and commerce, then he could not build it at all.

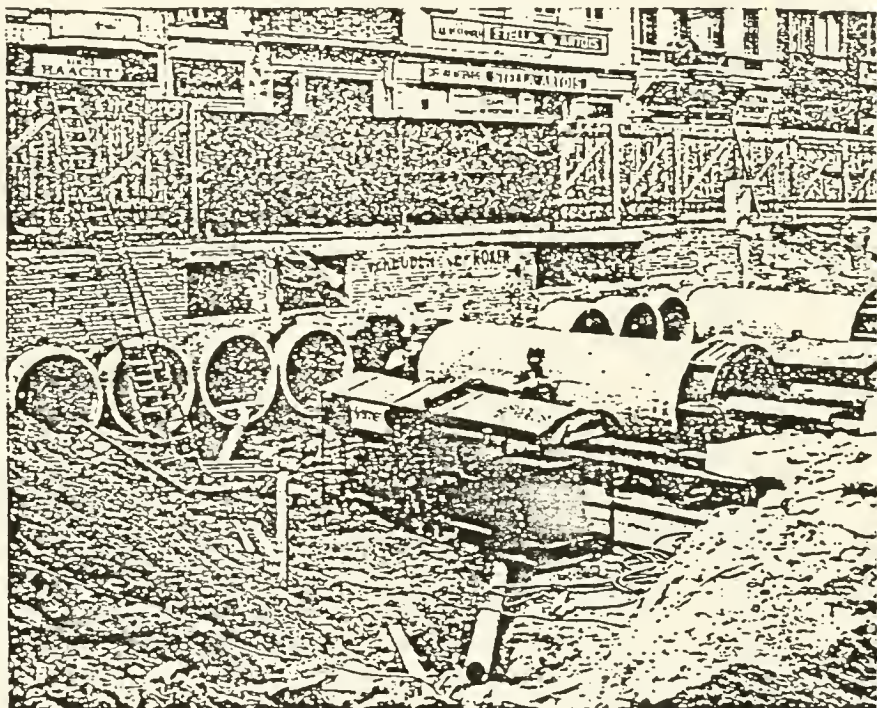
With that ultimatum, Wittemans and his staff halted work that had begun in 1970 and "searched for months to get an answer" to how to tunnel through the very dense sandy soil. They came up with two techniques: using a slurry mole where possible to bore tunnels (ENR 2/5/81 p 27) and jacking parallel pipes primarily to form station roof slabs while hardly disturbing the surface.

Since 1975 Belgian contractors have successfully used both methods to construct 8.4 km of tunnels and build 11 stations. Ten of those stations and a portion of tunnel are roofed with parallel pipes. Another 4.5 km with five stations is under construction or planned. A shorter section with five stations was built previously by the cut-and-cover method and is in use. All of the pipe jacking has been carried out by subcontractor Smet Boring, of Dessel, Belgium. The metro agency says it costs about 10% more than cut-and-cover.

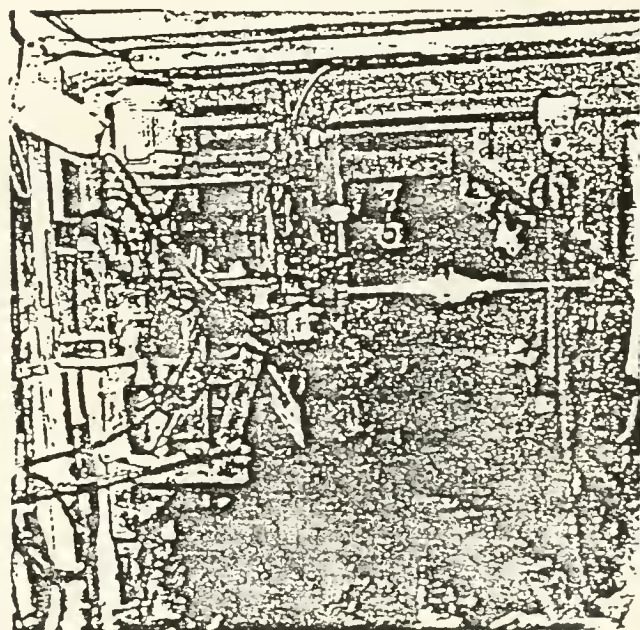
The \$330-million network is referred to as a premetro because streetcars using existing surface tracks dive into it downtown. Originally, the system was planned for heavy-rail coaches. But, in the 1970s, financial constraints and a re-evaluation of capacity needs brought a decision to use the lighter cars. The tunnels are designed with sufficient clearance so that they could rather easily be converted to heavy rail, however.

Since Antwerp's metro must compete for scarce government transportation funds, Wittemans' policy is to first complete the heavy construction of the entire network, figuring it will then be difficult for authorities to deny additional money for finishing touches. The next phase of work, slated to begin soon, will be construction of twin shield-driven tunnels under the Scheldt River, a \$20-million project that will take about 40 months. The 970-m bores, including approaches to the underwater section, will be driven by a slurry mole.

Minimal disruption. The pipe-jacking technique is essentially a modification of the Milan method in which walls are poured in trenches and a roof slab cast atop them in a shallow cut. The tunnel is then excavated below. With the Antwerp



Pipes driven under the street without breaking the surface are filled with reinforced concrete



Jacking frame normally drives pipe from a small excavated gallery

method, however, pipes are driven from excavated galleries, so there is virtually no penetration of the surface.

Wittebans says the Antwerp system is the first project to use parallel pipe jacking to build roof slabs. "People were jacking one length of pipe, but not doing what we are doing." Before proceeding on a large scale, his agency built a test section under a street in 1975. Six parallel tubes were driven 10 m at depths of 1.2 to 1.5 m. Based on the successful test, contractors began to use the technique to build stations.

To form roof slabs, the contractor drives large-diameter steel or asbestos-cement pipes—1.2 to 2 m—adjacent to each other from a small gallery. The crew mucks out tubes as they advance, places reinforcing cages and casts concrete within them. Joints between the tubes are sealed.

As pipe jacking proceeds at one end of a section, crews start excavating trenches at the other end for walls. Working

between sheet piles, they dig down manually at least 4 or 5 m from the galleries as winches remove the earth in buckets. When conditions permit, excavation is completed by the slurry-trench method, down to 10 or 12 m in the case of stations. Finally, crews mine out the tunnel with a loader and pour a floor slab.

Generally pipes are driven transversely about 13 m. But in two cases, the contractor drove them longitudinally in a flat arch configuration from a jacking area on falsework just under an adjacent pipe roof. On one job they penetrated 130 m. Two larger pipes at each side were almost completely cut away and crews drove sheet piles from those areas to pour the walls. They also cut off the lower halves of the other pipes and cast a roof slab within and below the remaining shells. The pipe bottoms had to be removed because the space

limitations on the jacking operation made them too low to act as a permanent ceiling. To complete the roof, the contractor excavated under the pipes and placed falsework. Then the crew removed the falsework in stages to cut the pipes with a torch and replaced the shoring. Workers again removed falsework in stages to cast the roof.

Pipes are placed about 10 cm apart. Depending on the size of the jacking gallery, they are driven in lengths of 1 to 5 m. The lead piece has a cutting edge that is adjusted by small jacks to keep the pipe on alignment, which is checked by a laser. The sections are coupled together and have a foam rubber seal between them.

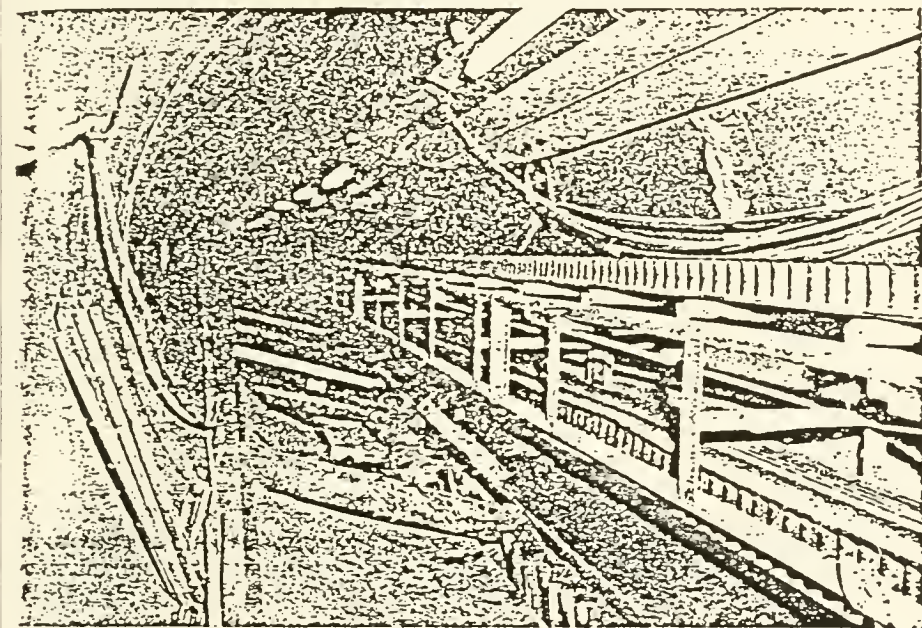
The lead pipe section has a small hole in it. As jacking and spoil removal progresses, a worker reaches through the hole, digs to the adjacent pipe and fills the space with bricks. When an entire tube has been driven, the crew pumps cement grout between the pipes. Once a set of tubes is in place, any remaining space around them is grouted.

Construction of the subway roof under Antwerp's historic main railroad station presented a particular problem. The station above imposed a load of 30 tons per sq m on the transit tunnel and station area below. To prevent subsidence during pipe jacking and mining, the contractor installed 148 large hydraulic jacks in the galleries under the rail station's foundations. Each supporting jack maintained pressures up to 600 atmospheres.

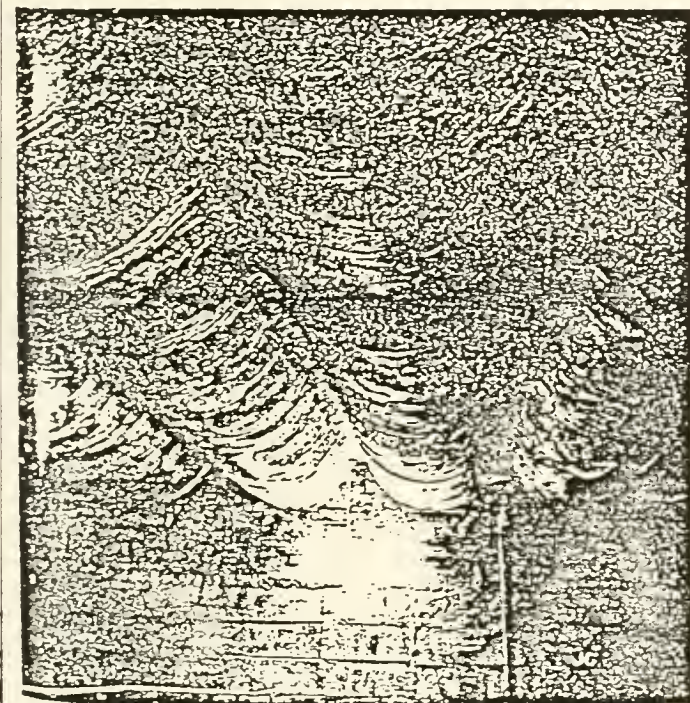
Waterproofing problems. Although the metro agency is pleased with pipe jacking, one aspect of the technique must still be refined: waterproofing the roof slabs. It is experimenting with several methods. In one test, bentonite clay that swells when it comes into contact with water is placed between the pipes with a steel plate below to keep it in place. In another, a plastic waffle drop-ceiling captures dripping water, which drains off at the sides. One problem with that method is the possibility of the plastic catching fire.

One of the most promising methods so far uses a waterproof seal made up of seven chemicals between the pipes. The whole roof is also coated with a porous foam layer that sucks up water like a sponge. The agency has several more years to test waterproofing methods before the still-unfinished stations come into use, but almost all the roofs are leaking. Wittebans admits that making the joints waterproof "is one of our most difficult problems."

Nevertheless, the metro's success with parallel pipe jacking is inspiring others. Smet Boring is negotiating with several Korean firms to apply the technique for an underground shopping center in Seoul.



Belt conveyor removes spoil from an advancing tube as workers dig it out at the end manually.



Finished roof requires waterproofing, which is still being tested.

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